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ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC-ETC(U)

JUL 81 K M LAURAITIS, J T RYDER, D E PETTIT

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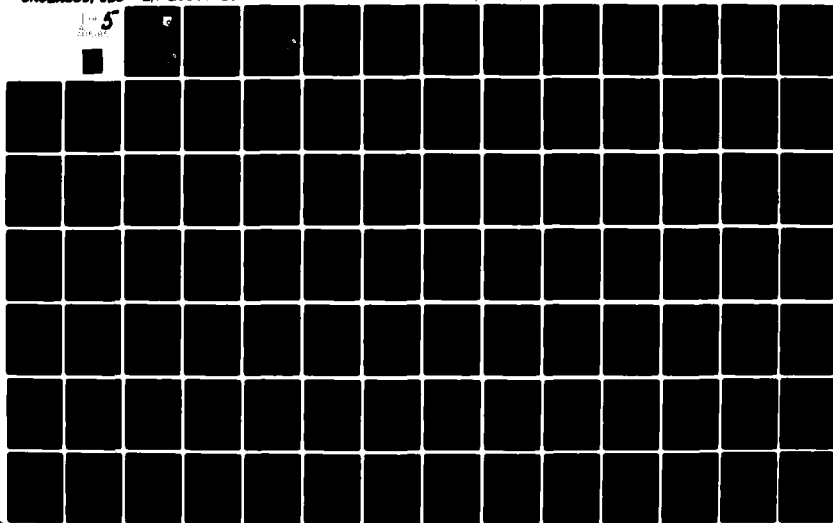
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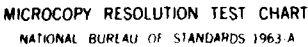
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VOLUME III

ADVANCED RESIDUAL STRENGTH DEGRADATION RATE
MODELING FOR ADVANCED COMPOSITE STRUCTURES
VOLUME III - APPENDIXES TO REPORT FOR TASKS II AND III



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Lockheed-California Company
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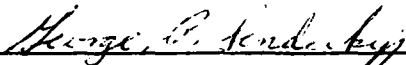
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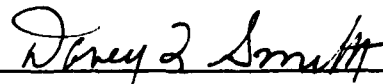
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This technical report has been reviewed and is approved for publication.



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents the results of the last two tasks of a three task program focusing on the study of relationship between damage propagation and residual strength of graphite/epoxy laminates. Specimens of two laminate types, a 32- ply quasi-isotropic and 24-ply 67%-0, containing a centered poorly drilled hole were evaluated in this study. Baseline static tension and compression tests were conducted at high and low strain rates and at elevated temperature. Com- pression tests were conducted for two restraint conditions, the full platen fatigue supports with 2.15 in. (55mm) window and 4-bar buckling supports.		

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Stress vs. life (S-N) fatigue data were generated at a stress ratio of $R = -1$ for each of the damaged laminates. Twenty replicate specimens for each laminate were fatigue tested to failure at a single stress level ($R = -1$) with the damage growth for each specimen monitored a minimum of ten times during its life to determine the fatigue life and damage growth distributions and pertinent statistical parameters. Based on these results, five cycle levels were selected for the residual strength study. Twenty-three specimens of each laminate were inspected, cycled to one of the five preselected N values and Holscanned again. Three of the replicates were destructively analyzed while the other surviving specimens were tested in static tension or compression. This sequence was repeated for each of the five N values.

Results indicated significant reduction in initial static tension and compression strengths due to the damaged hole condition and a further decrease in strength at the higher loading rate with a larger drop in compression than in tension. Fatigue cycling of the 24-ply specimens at ± 35 ksi (241 MPa) ($R = -1$) produced data which were dispersed over more than two orders of magnitude while data scatter was slightly more than one order of magnitude for the 32-ply coupons tested at a stress level of ± 22 ksi (152 MPa). As expected from the life data, damage growth for the 32-ply specimens was more well-behaved than for the 24-ply. However, large scatter in damage size was evident for both laminates and so no useful relationship between damage size and life could be established. Residual static properties of either laminate were not adversely affected by $R = -1$ fatigue cycling up to the 80% probability of survival life. Slight but insignificant increases (6-11%) in tensile residual strength and similar decreases in compression were noted for the 32-ply laminate. Both tension and compression residual strength tended to increase slightly as the number of cycles completed increased for the 24-ply laminate. Residual strength could not be related to damage size, not only due to the data dispersion but also because no definitive change in residual strength was observed.

A limited test program was conducted to assess the effect of different fatigue and environmental test conditions on residual strength and damage growth. The variables evaluated were: A) Specimen restraint (4-bar support); B) stress ratio, $R = -0.3$; and C) elevated temperature, 180°F (82°C). The Case A loading produced lives which were within the scatter band of tests conducted with the platen supports and very similar damage growth and residual strength behavior. Under the $R = -0.3$ loading both laminates completed 2 million cycles without failure. Most notable was the change in damage development, especially for the 24-ply laminate for which essentially no growth in the width direction was evident with extensive growth in the length direction. This longitudinal damage growth reduced the notch acuity resulting in significant increases in tensile residual strength with increasing number of cycles completed. Damage growth for the 32-ply laminate at $R = -0.3$ was also greater in the length direction, but growth in both directions did occur. For Case C, there appeared to be an order of magnitude decrease in life due to the elevated temperature exposure during cycling with more rapid initial growth for the 24-ply laminate. The life of the 32-ply laminate appeared to be shortened also but not as severely.



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PREFACE

This report has been issued in three volumes. Volume I details the work completed under Task I, Preliminary Screening. Volumes II and III encompass the last two tasks of the investigation into the delamination growth and residual strength behavior of initially damaged graphite/epoxy laminates. Volume II includes the results of Task II - Damage Growth and Residual Strength Degradation Prediction and Task III - Effect of Fatigue Loading/Environment Perturbations. The tabulated data for these tasks are available in this volume of appendixes, Volume III.

The work reported herein was accomplished under Contract F33615-77-C-3084, Project 2401, Work Unit 24010117, sponsored by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433. Dr. G. P. Sendeckyj, AFWAL/FIBE, was the Air Force Program Monitor.

The program which was conducted by the Structures and Materials Department of the Lockheed-California Company, was directed by the Co-Principal Investigators, Ms. K. N. Lauraitis and Mr. D. E. Pettit of the Fatigue and Fracture Mechanics Laboratory. Analytical and conceptual assistance was provided by Dr. J. T. Ryder of the same laboratory. The support and contributions of the Materials Laboratory personnel, Mr. W. E. Krupp, Group Engineer, Mr. R. C. Young, Specimen Fabrication, Mr. S. Krystkowiak, Fractography, and the Fatigue and Fracture Mechanics Laboratory Personnel, Mr. J. M. Cox, Data Reduction, Mr. D. Diggs, Mr. P. Mohr, Mr. F. Pickel, Mr. W. Renslen, Mr. L. Silvas and Mr. C. Spratt in the area of Mechanical Testing are gratefully acknowledged.

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APPENDIX A

Quality Control Plan

QUALITY CONTROL PLAN

This Quality Control Plan has been prepared in compliance with the U. S. Air Force contract F33615-77-C-3084.

Manufacturing and quality assurance procedures will be applied to material and laminates, as described below, to ensure quality, uniformity and traceability of test specimens.

1. Material Acquisition

Narmco T300/5208 graphite/epoxy prepreg material conforming to Lockheed Material Specification C-22-1379/111 will be acquired for this program in three procurements. A new material batch will be obtained for each of Task I, II, and III. Other materials required for the fabrication of test laminates will be purchased to the requirements given in the Lockheed Engineering Purchasing Specification (EPS) Manual, to the extent indicated in Section 3. Fiberglass for the specimen tabs will be acquired to Lockheed Material Specification LCM C-22-1032/141.

2. Material Acceptance

The prepreg material supplier will be required to provide a certificate of conformance, including test data, resin/catalyst age, and date of mixing with each delivery. Lockheed Quality Assurance laboratories will then conduct acceptance tests on the delivered material in confirmation of supplier data. These tests will include:

- Uncured Properties
 - Fiber orientation
 - Resin content
 - Volatiles content
 - Resin flow
 - Gel time
 - Infrared Analysis
 - Areal Weight

- Mechanical and Physical Properties of Cured Material
 - Void Content
 - Specific Gravity
 - Cured Resin Content or Fiber Volume
 - Interlaminar Shear
 - Longitudinal Tensile Strength and Modulus
 - Longitudinal Flexural Strength and Modulus
 - Cured Ply Thickness

The test methods and acceptance limits shall be as specified in the applicable material specifications, C-22-1379/111 and C-22-1379A. Materials not conforming to the requirements of the Specifications will be rejected.

Material specifications further stipulate preparation-for-delivery provisions covering date of shipment, allowable time and temperature in transit, and vapor-tight packaging required for supplier and transporter conformance. Materials requiring refrigerated storage will be placed in Quality Assurance-approved refrigerators immediately upon receipt. Pending acceptance by the Quality Assurance laboratory, all materials will be kept segregated and withheld from use. After acceptance, each container, roll, or spool of material will be stamped or otherwise approved by Quality Assurance and controlling labels will be attached.

3. Material Processing

This section establishes the requirements and procedures for the lamination of graphite/epoxy (T300/5208) test panels, fabrication of glass/epoxy tab stock and bonding of tabs to coupons.

3.1 Applicable Documents and Materials

The following documents form a part of this procedure to the extent specified herein.

3.1.1 Lockheed Materials Specifications

Lockheed Material Specification, C-22-1379A Graphite Fiber Non-Woven Tape and Sheet, Resin Impregnated, General Specification for.

Lockheed Material Specification C-22-1379/111 Graphite Fiber Non-Woven Tape and Sheet, 350 ksi Strength, 33 MSI Modulus, 350°F Curing, Epoxy Preimpregnated.

Lockheed Material Specification LCM C-22-1032/141 Glass Fabric/Epoxy Pre-impregnated, 350°F Cure.

3.1.2 Commercial Materials

3.1.2.1 The following commercial materials, covered by the Lockheed Engineering Purchasing Specification (EPS) Manual, form a part of this procedure to the extent specified herein.

<u>Material</u>	<u>EPS Item No.</u>
Vacuum Bag Nylon Film	22.9001
Parting Agent Film	22.9004
Porous Release Cloth	22.9030
Peel Ply	25.5910
Stick Contact Adhesive	30.0650

3.1.2.2 The following commercial materials not covered by the Engineering Purchasing Specification Manual are required for use in this procedure.

American Cyanamid Co.	FM-400 Epoxy Adhesive Film, 0.07 lbs/ft ² , 350°F Cure
Air Tech International Inc.	Flashbreaker 5 Pressure Sensitive Tape

3.2 Material Control

All materials shall conform to the applicable specifications.

3.2.1 Storage and control requirements shall be as specified in Table A1. Refrigerated material shall be stored in sealed, moisture vapor proof containers.

3.2.2 Refrigerated materials shall be thawed until moisture no longer condenses on the moisture-proof containers.

3.2.3 All perishable materials shall have had validation tests performed within 30 days of use, if initial storage time limit has been exceeded. Validation tests are the same as those shown in Table A1.

3.2.4 A manufacturer's identified defects (MID's) record is furnished with each roll of Gr/Ep by the material supplier. This record shall be furnished to the Composites Laboratory with each roll of Gr/Ep.

3.2.5 Stored perishable material in which visible water is observed in the bag shall be rejected.

TABLE A1 - MATERIAL CONTROL

Material	Max. Storage Temp.	Maximum Storage Time Before Retesting, Day		Minimum Required Tests	Max. Allowed Out Time During Proc. @75°F & 55% R.H.
Gr/ep Prepreg	0°F	180	60	⚠ ⚠	14 days
Adhesive Film	0°F	180	90	Climbing Drum Peel @ -65°F	10 days

① Flow and gel time, room temp. flexural and short beam shear, specific gravity and resin content.

② See applicable Material Specifications for test methods and requirements.

3.3 Environmental Control

3.3.1 All work shall be done in controlled areas to avoid degradation of the materials and laminates. Temperature shall be between 65-80°F and relative humidity shall not exceed 55%.

3.3.2 All incoming air into controlled areas shall be filtered by at least a 1½-inch thick throw-away type or permanent washable type filter or by an equivalent method. Inspect and clean filters monthly.

3.4 Tooling

3.4.1 All tools shall be designed and coordinated to produce parts that meet all requirements of this specification and the Engineering drawing. Tools shall have the minimum mass necessary for dimensional and thermal control.

3.4.2 All tool plates used for curing laminates shall be aluminum. Thickness of the caul plate shall be 0.500 in. with a tolerance of ± 0.003 in., flat and parallel. Caul plates used on top surface of laminate under the vacuum bag shall be aluminum sheet 0.064 in. standard thickness.

3.4.3 Tooling parting agents and cleaners shall not contaminate the laminates or interfere with subsequent bonding, finishing and inspection.

3.5 Material Preparation

3.5.1 Templates or patterns shall be placed on the prepreg in such a way as to ensure that the fiber direction is in accordance with Engineering drawing requirements and does not include any MID's flagged by the supplier (see 3.2.4)

3.5.2 Panels will be laid-up such that the edges of tape are parallel or perpendicular to the required fiber direction within 1°.

3.5.3 All areas from which material will be cut shall be checked prior to cutting for the defects defined in C-22-1379, Quality and Condition Requirements, which may not have been flagged by the manufacturer. Material containing unacceptable defects will not be used. Patch plies are not permitted.

3.5.4 Plies shall be cut with sufficient care so as not to disorient fibers. Cutting tools shall be cleaned prior to use on preregs.

3.5.5 No ply end butt splices are permitted in the laminate assembly.

3.6 Tool Preparation

3.6.1 The tool molding surfaces shall be solvent wiped and all resin removed prior to layup.

3.7 Panel Lay-up

3.7.1 The preimpregnated graphite tape shall be placed on the tool in the sequence and orientation specified on the Engineering drawing or Engineering Test Request. As each ply is placed on the assembly, it shall be checked for the defects defined in C-22-1379 prior to applying the ply firmly in place. A check-off system shall be used to assure proper orientation and stacking sequence of each ply.

3.7.2 The surface of each ply shall be wiped with a teflon, polyethylene or equivalent device to give maximum adhesion to the previous ply. Wiping shall be done only in the direction of the fibers to prevent fiber separation and distortion. Wiping the surface should be done only when the orientation of the tape edge has been verified to be within $\pm 1^\circ$ of the drawing requirement. Excessive pressure shall not be applied during wiping and wiping shall be kept to a minimum.

3.7.3 Parallel plies shall be laid up so that edge splices are staggered a minimum of 1.0-inch in adjacent plies and not coincide within a 5 ply thickness.

3.7.4 Edge splices shall be butted flush, ± 0.03 inch.

3.7.5 Entrapped air in blisters that cannot be wiped out without distorting fibers shall be removed by puncturing the blister with a needle or pointed sharp blade as often as needed and wiping in the direction of the fibers toward the puncture. Care shall be taken not to damage the under ply fibers.

3.7.6 Where permanent edge steps or dams are not incorporated in the tool for edge thickness control, an edge dam shall be built around the perimeter of the laminate. The dam shall not be more than 0.06-inch from the laminate edge and shall be of sufficient height to enclose the laminate. The bleeder may not extend over the dam surface. Joints in the dam shall be kept to a minimum. Dam joint gaps shall not exceed 0.03-inch.

3.7.7 A dry peel ply of fabric (EPS 25.5910) or equivalent shall be placed on both sides of the layup and wiped smooth.

3.7.8 A bleeding and bagging system of the following construction shall be used.

- (a) Cure plate
- (b) Separator film - perforated parting agent film or porous release cloth.
- (c) Mochburg CW1850 bleeder paper (1 ply for 4 plies of prepreg.)
- (d) One ply of porous Teflon-coated glass cloth (DuPont Armalon)
- (e) Nylon peel ply
- (f) Graphite/epoxy laminate
- (g) Nylon peel ply
- (h) One ply Armalon
- (i) Mochburg CW1850 bleeder paper (4:1 ratio)
- (j) Release film
- (k) Caul plate (aluminum)

- (l) One ply Mochburg CW1850
- (m) Release film
- (n) Glass breather
- (o) Nylon film vacuum bag placed over the laminate and sealed to the tool face.

3.7.9 Curing - Pressure and cure cycle should be within the limits given in Table A2.

TABLE A2 - CURE CYCLE

- | |
|--|
| <ol style="list-style-type: none"> 1. Apply full vacuum 2. Heat to $275^{\circ} \pm 5^{\circ}\text{F}$ @ $2-3^{\circ}\text{F}/\text{min}$. *3. Dwell @ $275^{\circ} \pm 5^{\circ}\text{F}$ for 30 ± 1 minutes 4. Apply 100 ± 5 psi vent vacuum to air @20 psi. 5. Heat to $355 \pm 5^{\circ}\text{F}$ @ $2-3^{\circ}\text{F}/\text{min}$. 6. Cure for 120 ± 10 min. @ $355 \pm 5^{\circ}\text{F}$. 7. Cool to $140 \pm 5^{\circ}\text{F}$ under pressure @less than $4^{\circ}\text{F}/\text{min}$. 8. Cool to room temperature. <p>* NOTE: Dwell time started when temperature reaches 265°F.</p> |
|--|

3.8 Laminate Control Specimens

Each panel will be laid up to contain an excess strip at least one inch wide and running either the length or width of the panel. The strip must be located at least one inch from the panel edges.

3.8.1 Laminate control coupons will be cut from this strip for the determination of resin content, specific gravity and average ply thickness. Test requirements are given in Table A3.

3.8.1.1 Void volume fraction will also be measured on laminate control coupons from selected panels using standard metallographic techniques. This method will be used to confirm results calculated from the acid digestion and density measurement values.

TABLE A3 - TEST REQUIREMENTS

<u>Test</u>	<u>Requirements</u>
Fiber Volume	65 \pm 2%
Specific Gravity	1.56 - 1.60
Thickness/Ply	.0046 - .0053 inch (Report for information only)

3.9 Workmanship

All laminated details and bonded assemblies shall be of highest quality. Conditions in excess of the following shall be cause for rejection.

3.9.1 There shall be no evidence of surface cracking, uncoated fibers, excess resin, pits, tackiness or other indications of defective resin characteristics or distribution.

3.9.2 No visual delaminations are allowed.

3.9.3 The laminate shall be essentially void free. Calculated voids shall not exceed 1.0 volume percent without special engineering review.

3.9.4 Wrinkles

3.9.4.1 No wrinkles containing graphite fibers are permitted. Resin wrinkles caused by peel ply gathering or by the bleeder system shall not be cause for rejection if the resin ridge can be removed without damaging the graphite fibers using 320 grit or finer sandpaper.

3.9.5 The presence of foreign material, e.g., separator film, masking tape, etc., in the part is not acceptable.

3.9.6 There shall be no sharp or frayed edges, nor edge delaminations resulting from trimming and routing operations.

3.10 Cleanup

Chemical strippers shall not be used in any way to remove excess resin or adhesive. If removal is necessary, it shall be done with an abrasive, and shall not damage any surface graphite fibers.

3.11 Records

The following records are required for permanent retention and traceability.

1. Temperature-pressure-vent-time profile record for each cure cycle.
2. Thermocouple locations.
3. Material batch and roll number, acceptance laboratory report number and cumulative out-time up to the time of vacuum application.
4. A completed autoclave record sheet as shown in Figure A1.

3.12 Machining of Test Specimens

Specimens are to be machined using aluminum backup sheets to the dimension shown in Figure A2, Drawing TL 1038. Specimen cuts will be made parallel to the panel edge to ± 1 degree. Cutting rates will be chosen to minimize edge damage. Specimen dimensional tolerances and inspection requirements are given in the Task I Test Plan. All specimen shall be weighed and the weight recorded on the specimen checklist form following fabrication.

3.13 Fabrication and Bonding of Glass Fabric/Epoxy Grip Tabs

3.13.1 Grip tab sheet material shall be fabricated by laminating the required number of plies of Style 181, 1581, or 7581 glass fabric/epoxy prepreg. For most standard coupons, the laminate consists of 6 plies or 3 plies in thickness depending on the type of coupon. Thicknesses and other dimensions shall be in accordance with Lockheed Drawing No. TL 1038. Tab dimensions shall be as specified on specimen drawing.

Figure A1: Sample Autoclave Record

Run # _____

ETR/Dwg.# _____ Panel I.D. _____ Matl. Code _____

Q.A. Lab. Report # _____ Made for _____ Date _____

I. Description of Materials

Designation _____ Batch# _____ Roll# _____ Date _____

No. of Plies _____ Orientation _____

CURE CYCLE (NARMCO)

II. Cure Press. _____ psi

Cure Temp _____ °F

Cure Time _____ min.

Vac. Bag _____ inch-Hg

1. Apply fuel vacuum
2. Heat to $275^{\circ} \pm 5^{\circ}\text{F}$ @ $2-3^{\circ}\text{F}/\text{min}$.
- *3. Dwell @ $275^{\circ} \pm 5^{\circ}\text{F}$ for 30 ± 1 min.
4. Apply 100 ± 5 psi & vent vac to air @ 20 psi.
5. Heat to $355 \pm 5^{\circ}\text{F}$ @ $2-3^{\circ}\text{F}/\text{min}$.
6. Cure 120 ± 10 min. @ $355 \pm 5^{\circ}\text{F}$
7. Cool to $140 \pm 5^{\circ}\text{F}$ under press. @ $<4^{\circ}\text{F}/\text{min}$.
8. Cool to R.T.

III. Autoclave Pressurization

Time @ start _____

Time @ press. _____

Delta Time min. _____

IV. Temp _____ °

* NOTE: dwell time starts when temp reaches 265°F .

V. Temp _____ °F @ lay-up

V. %R.H. _____ @ lay-up

VI. TIME RECORD

	1	2	3	4	5
	Temp	Temp	Temp	Temp	Temp
	Time	Time	Time	Time	Time
Start heat					
At temp.					
Time to temp min.					
Time @ temp min.					
Heat-up rate °F/min.					
Cool-down rate °F/min.					

VI. Panels

I.D.	Size(in.)	No.	Meas.
	____x____	Plies	Thick

IX. Comments

VIII. Bleeding & Bagging

_____ nylon bag
_____ 18l glass breather
_____ vac pac
_____ Mochburg (1 ply)
_____ caul plate
_____ vac pac
_____ Mochburg (4:1 ratio)
_____ armalon
_____ nylon peel ply
_____ LAMINATE
_____ nylon peel ply
_____ armalon
_____ Mochburg
_____ vac pac
_____ cure plate

Signature of Inspecting Engineer

A12

NOTE: Laminate completely damaged
perforated vac pac taped to dam.

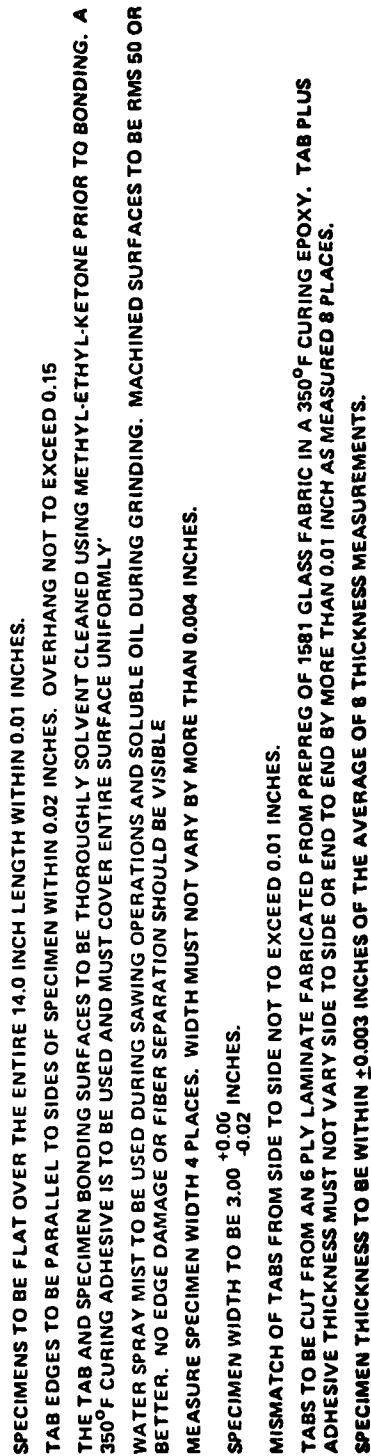


FIGURE A2: 3-INCH WIDE SPECIMEN CONFIGURATION, DRAWING T1038

3.13.2 The material used for grip tab stock shall be glass/epoxy prepreg conforming to Lockheed Material Spec. LCM C-22-1032/141. This material shall be cured at 350°F for one hour under a pressure of 35 psi plus vacuum. A caul sheet shall be used under a vacuum bag for pressure application.

3.13.3 The adhesive used for bonding tabs to coupons shall be American Cyanamid Co. FM-400, 0.07 lbs/ft². Aluminum caul plates $\frac{1}{4}$ to $\frac{1}{2}$ -inch thick shall be used to apply bonding pressure on tabs. Cure adhesive at 350°F \pm 5°F for 60 to 70 minutes using 15 \pm 1 psi positive pressure on bondline (no vacuum). Cool to 170°F under pressure.

4. QUALITY ASSURANCE PROVISIONS

To produce test panels of consistent quality, strict adherence to all the minimum Engineering requirements of Section 3 is vital. The requirements of Section 4 are intended to outline the minimum amount of inspection and surveillance before, during, and after processing testing to confirm that adherence has been achieved.

4.1 Material

Verification shall be made that only adhesives and prepreg materials are used that are approved to the material specifications specified.

4.1.1 Adhesive or prepreg material which is stored below room temperature shall be wrapped in a closed impermeable bag at all times. Evidence of material cracking or moisture condensation on the material is cause for rejection. Exposure to ambient temperature shall be minimized.

4.1.1.1 Adhesive or prepreg material which is withdrawn from storage and left out 30 minutes or more before returning to the box, shall have the out-time marked on an appropriate tag attached to the roll. Material for which accumulated out-time at ambient temperature exceeds the allowable out-time given in Table A1, shall not be used.

4.1.2 All adhesive and prepreg materials shall be controlled as to batch, lot, and roll numbers for traceability.

4.1.2.1 Material which has exceeded the allowable storage shall not be used unless tested within one week prior to use.

4.1.2.2 All refrigerated materials shall be checked for compliance to 3.2.2 prior to use.

4.2 Panels and coupons shall be clearly marked before and after application of tabs to indicate the bag side of the graphite/epoxy laminate as originally cured. Panels shall be identified with a number including material code and autoclave run number. Coupons shall be identified with panel number from which cut and a dash number indicating location.

Example: 1LY 556-1A

Coupons shall be numbered consecutively as they are cut from panels to indicate relative location in the panel.

4.3 Equipment and Facilities Control

Equipment and facilities used for materials storage, processing, and inspection shall be controlled in accordance with LCP79-1053.

4.4 An effective quality control system shall be provided to ensure compliance with the requirements of this procedure as specified in the following sections.

4.4.1 Material Acceptance testing will be performed by Lockheed Quality Assurance Laboratories.

4.4.2 Panel and tab fabricating and tab bonding will be accomplished by personnel of the Composites Laboratory at Rye Canyon Research Laboratories. Layup and cure of each panel will be witnessed and inspected by Engineering.

4.4.3 Specimens will be machined to required dimensional tolerances by machinists at the Rye Canyon Shops. Dimensional inspection of specimens will be the responsibility of Lockheed Quality Assurance.

4.4.4 The principal investigator will have final acceptance/rejection authority for material, panels and specimens.

4.4.5 An engineering approved autoclave record will be maintained for each panel.

4.4.6 A Quality Assurance specimen checklist such as shown in Figure A3 shall be completed for each specimen verifying its conformance with the requirements of the Quality Assurance Plan and Test Plans.

4.5 Non-Destructive Inspection

4.5.1 All test panels shall be non-destructively inspected for internal defects by ultrasonic "C" Scan procedure. Standard reference 2 mil thick teflon pads of 1/8-inch to 1/4-inch diameter will be placed at one corner of each panel. A permanent record of the C-Scan results shall be retained with the records required in 3.11.

4.5.1.1 Specimens will not be cut from areas in the panels which show indications comparable to the standards.

4.5.2 Location and size of holes and intentionally induced defects will be measured by Engineering based on Holosonics Series 400 Holoscan results.

Figure A3. Sample Specimen Checklist

Date: _____

Specimen No. _____ Laminate Type _____
 No. of Plies _____ Required Orientation _____

<u>Acc.</u>	<u>Rej.</u>	<u>Measured</u>	<u>Req'd</u>	<u>Date</u>	<u>Spec. Wt.</u>
<input type="checkbox"/>	<input type="checkbox"/>	1. % Fiber Vol. _____	65 ± 2%	_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	2. % Resin Vol. _____	35 ± 2%	_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	3. % Void Cont. _____		_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	a. by density _____	< 1%	_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	b. by metallography _____	< 1%	_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	Specimen Thickness: _____		_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	Avg. Thk. _____ Max. Deviation _____	Req'd Dev.: ±0.003		
<input type="checkbox"/>	<input type="checkbox"/>	Specimen Width _____		_____	_____
<input type="checkbox"/>	<input type="checkbox"/>	Avg. Width _____ Max. Deviation _____	Req'd Avg: 300 ± 0.00 , 0.02 ,		
			Dev: ± 0.002		
<input type="checkbox"/>	<input type="checkbox"/>	Tab Mismatch _____	Req'd: less than 0.01 in.		
<input type="checkbox"/>	<input type="checkbox"/>	Tab parallelism _____	Req'd: within 0.02 inches		
<input type="checkbox"/>	<input type="checkbox"/>	Tab overhang _____	Req'd: less than 0.15 inches		
<input type="checkbox"/>	<input type="checkbox"/>	Edge damage or fiber separation _____			

_____ gm. Specimen weight following fabrication.

_____ Date weight measured.

APPENDIX B

Specimen Weight Measurements

TABLE B1
WEIGHT MEASUREMENTS^a FOR
FATIGUE LIFE DISTRIBUTION SPECIMENS - TASK II

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
HC-26	187.2	186.8	MB-17	231.9	232.5
IB-13	191.2	190.5	QA-8	234.1	233.1
CC-25	190.4	-	LC-30	230.7	232.0
DA-6	190.2	189.8	JC-24	229.9	231.1
AC-30	191.4	-	SA-6	230.1	230.0
BC-29	192.4	191.8	PA-5	231.8	230.3
FA-3	191.7	192.5	SC-30	228.9	231.3
AA-2	191.1	191.1	KC-23	233.1	231.1
EA-6	189.4	189.7	NA-3	235.4	231.9
HC-27	188.3	188.3	MC-27	232.4	231.2
IC-25	190.0	189.5	RA-8	232.8	231.6
CA-1	191.9	192.0	QC-29	234.1	233.2
BB-17	191.1	191.2	LC-24	231.3	230.6
DC-30	190.6	190.6	PB-19	233.0	233.5
GC-27	183.3	183.4	JA-1	229.4	233.2
EB-16	191.9	190.5	SC-24	228.6	229.2
AB-15	191.5	192.9	JA-6	235.5	234.5
IB-19	191.7	191.3	PC-23	231.5	231.2
DC-28	191.6	190.9	LA-6	230.4	231.9
FC-23	192.3	103.1	RB-14	228.6	232.3

a = Listed in order tested.

TABLE B2
WEIGHT MEASUREMENTS^a FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N₅
TASK II

24-PLY N ₅ = 40,000 CYCLES			32-PLY N ₅ = 28,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
GA-9	187.6	188.8	KA-5	233.3	233.3
BC-25	189.4	190.9	PB-13	234.6	232.0
HB-3	188.7	b	RA-5	231.8	231.6
CB-19	192.3	192.5	JC-23	230.7	231.5
DC-26	190.7	b	MA-4	230.8	232.4
GA-3	189.9	b	PB-12	232.6	233.2
FC-27	194.5	193.2	NB-14	230.8	234.3
HC-30	188.8	187.6	QC-31	233.3	232.7
BC-26	189.9	b	SB-18	233.1	232.3
EB-15	190.2	b	KB-14	231.4	232.1
CA-3	190.8	b	LC-26	232.2	233.2
CC-27	190.0	190.6	PA-7	232.6	232.8
AA-8	187.6	b	SB-17	231.4	230.5
DB-13	191.2	b	JB-18	233.2	233.8
IB-16	193.2	191.8	RC-25	231.9	232.1
CC-24	190.6	192.0	LB-19	233.4	232.3
AC-26	193.2	193.7	NB-18	233.5	234.5
FA-7	194.8	b	RC-31	231.2	232.2
GA-1	183.4	b	MB-15	234.6	233.6
EA-9	188.3	189.5	KB-17	230.9	232.0
GB-15	191.1	191.1			

a = Listed in order tested
b = Failed in fatigue

TABLE B3
WEIGHT MEASUREMENTS^a FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N_4
TASK II

24-PLY N_4 = 20,000 CYCLES			32-PLY N_4 = 20,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
BC-28	192.1	b	NB-17	232.5	233.5
HC-29	187.4	b	JB-15	231.4	233.1
AC-25	191.6	185.3	QC-30	230.1	232.2
HB-12	189.7	b	LA-5	232.4	232.0
GC-24	190.6	188.9	MB-18	229.5	231.8
BA-8	189.1	b	SC-23	232.1	231.0
FB-15	193.4	190.9	RC-24	230.3	230.9
EC-26	190.7	b	LA-4	231.4	230.0
IB-14	190.2	b	MB-13	231.8	232.8
CB-17	191.8	191.0	KB-12	232.0	231.3
CA-9	187.5	b	NA-6	232.4	233.4
GC-25	198.2	198.4	RC-22	229.7	231.3
AA-3	191.5	192.8	PB-17	234.4	233.2
BB-14	192.2	192.7	SA-9	234.3	b
DB-14	192.4	190.3	JB-11	234.5	234.7
FA-2	190.4	191.6	QC-22	232.5	232.0
FC-29	190.6	191.7	SC-27	230.2	230.4
EB-17	188.8	b	LC-31	233.2	230.0
AB-17	188.7	b	MB-11	229.1	230.0
CA-4	194.4	b	QB-13	233.4	232.7
BC-22	190.8	b	RA-7	231.5	231.7

a = Listed in order tested

b = Failed in fatigue

TABLE B4
 WEIGHT MEASUREMENTS^a FOR
 SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N₃
 TASK II

24-PLY N ₃ = 12,000 CYCLES			32-PLY N ₃ = 10,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
DB-15	188.9	189.7	SA-5	230.9	231.9
AC-27	191.5	192.3	PA-4	235.3	234.8
DA-10	185.4	187.6	LA-7	231.2	231.8
BC-21	192.0	191.3	PA-1	230.5	233.1
FB-18	188.6	b	NB-16	231.4	235.6
CA-6	187.7	b	KA-7	235.1	232.9
IA-2	189.6	189.8	MC-29	231.0	231.5
EA-4	191.1	b	QB-12	231.8	231.6
GB-18	190.4	189.3	RB-12	231.2	231.7
HB-9	190.7	b	LC-27	231.6	234.5
DA-2	190.5	b	SA-3	232.3	231.7
AA-5	192.0	192.8	JC-28	233.1	233.2
CB-14	189.9	189.9	NB-13	231.8	233.4
HC-21	189.1	188.6	KC-22	230.2	233.4
GA-5	189.9	189.6	MC-25	232.0	232.5
IA-6	190.9	190.0	LC-23	229.7	233.6
FA-1	189.6	190.1	SB-11	230.4	230.6
BB-19	191.6	191.3	QC-23	231.8	234.4
IA-8	190.9	190.5	JC-27	233.6	235.5
CA-2	189.7	192.4	PC-27	232.3	234.5
HA-6	187.8	188.0			

a = Listed in order tested

b = Failed in fatigue

TABLE B5
WEIGHT MEASUREMENTS^a FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N₂
T'SK II

24-PLY N ₂ = 8,000 CYCLES			32-PLY N ₂ = 5,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
FC-26	193.3	193.2	MB-16	231.6	232.9
DC-29	189.5	190.6	NC-26	234.6	234.0
AA-9	189.9	b	KC-28	232.5	232.1
BC-30	191.5	191.6	QA-1	230.8	231.8
GC-22	187.8	186.9	JA-4	231.3	233.2
AA-7	192.6	192.2	QA-9	232.7	234.2
IB-15	190.7	190.9	SB-13	230.0	232.1
FB-11	192.0	191.8	NC-22	230.2	233.5
CB-16	192.1	191.2	KB-16	232.9	233.7
EC-24	188.3	188.8	LA-2	229.2	233.2
BB-12	192.1	b	PB-15	233.6	230.8
DA-5	190.9	189.9	RB-20	228.7	229.6
GA-6	189.7	189.4	MA-6	232.4	231.6
HB-16	191.2	190.3	RC-27	229.1	232.9
DB-18	188.8	188.7	JA-5	235.4	234.5
HB-15	192.1	b	LB-16	231.3	235.1
BA-6	190.4	b	KC-24	228.8	230.2
CB-12	189.2	189.8	PC-25	230.2	232.1
AC-24	191.3	192.8	NA-2	233.1	233.0
EA-5	188.3	188.7	QC-28	232.2	233.1
EC-29	188.1	188.0			
IC-27	188.8	190.4			

a = Listed in order tested
b = Failed in fatigue

TABLE B6
WEIGHT MEASUREMENTS^a FOR
SPECIMENS TESTED FOR RESIDUAL STRENGTH AFTER FATIGUE CYCLING TO N₁
TASK II

24-PLY N ₁ = 4,000 CYCLES			32-PLY N ₁ = 1,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
EA-7	187.1	189.2	LA-9	229.8	231.1
HC-24	188.6	190.2	QA-6	232.8	234.0
CC-23	190.3	191.9	NA-4	233.7	234.1
GB-16	190.2	191.6	SB-19	229.1	231.5
FC-25	193.8	194.5	MA-8	230.7	232.1
BA-9	187.8	189.5	KC-27	230.2	232.1
DA-3	191.2	192.4	JB-13	232.6	234.1
AB-13	188.3	191.3	PA-3	232.4	232.9
IA-1	190.1	189.7	MC-28	232.6	230.8
EC-27	189.5	190.1	SA-7	230.1	232.4
FC-24	191.8	193.6	PA-9	232.8	232.3
GA-4	187.8	190.5	QB-17	231.4	231.7
BA-1	186.8	188.9	NC-30	232.7	233.6
EC-25	190.6	191.9	RA-2	233.9	232.4
DC-22	186.4	189.7	RA-9	233.9	232.7
AC-29	192.1	193.4	JC-22	230.8	231.3
HA-7	188.6	190.3	LA-3	230.1	234.4
AB-14	191.4	193.4	NC-28	230.5	232.4
HA-2	189.1	190.2	JB-16	232.6	233.4
FB-19	190.2	191.4	KB-18	232.4	233.7

a = Listed in order tested

TABLE B7
WEIGHT MEASUREMENTS^a FOR
FATIGUE LIFE DISTRIBUTION SPECIMENS - TASK III

24-PLY N_4 = 20,000 CYCLES			32-PLY N_4 = 20,000 CYCLES		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
FATIGUE CONDITION A - 4 BAR SUPPORT					
AA-8	192.2	192.6	DC-27	238.0	237.3
BC-23	193.6	193.2	EB-18	236.2	236.7
CA-6	197.9	197.7	FA-3	232.7	230.5
			FA-8	232.3	233.7
FATIGUE CONDITION B - R = -0.3					
BC-24	195.9	194.6	FC-30	232.3	232.4
CC-27	190.7	191.6	EA-8	235.0	-
AB-11	190.9	190.6	DC-31	237.7	238.0
FATIGUE CONDITION C - 180°F (82°C)					
BB-12	191.2	193.4	FB-19	233.0	233.5
CA-4	199.3	199.6	DC-28	234.6	233.6
AA-4	190.6	192.2	EB-15	236.1	337.0

TABLE B8
WEIGHT MEASUREMENTS^a FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION A^b
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
$N_1 = 4,000$ CYCLES			$N_1 = 1,000$ CYCLES		
BA-7	191.9	191.8	DB-13	235.7	236.3
AB-14	190.4	192.2	EA-1	239.4	230.6
CA-9	189.5	191.1	FC-28	236.6	234.9
CA-2	190.4	191.0	FC-23	233.3	233.0
AC-26	190.6	191.6	EC-22	235.8	231.9
BC-27	196.7	198.0	DC-26	239.2	238.2
$N_2 = 8,000$ CYCLES			$N_2 = 10,000$ CYCLES		
CC-29	190.8	192.5	SC-23	237.4	237.6
BA-4	191.0	190.6	FB-14	231.5	231.4
AB-16	192.1	192.2	EB-17	237.1	236.2
CA-10	191.9	191.1	FA-10	233.7	231.8
CA-7	192.4	191.0	EA-7	237.0	233.8
AB-19	191.5	191.1	DB-18	235.6	234.2
$N_3 = 12,000$ CYCLES			$N_3 = 20,000$ CYCLES		
BB-11	192.6	192.6	DB-11	237.5	236.8
CC-21	191.0	191.5	FA-1	238.0	237.1
AA-7	193.6	190.7	EB-20	237.5	236.2
AC-31	195.8	197.4	DA-3	235.7	236.6
CC-26	190.8	190.2	EC-23	236.0	233.7
BB-13	196.5	196.5	FA-2	232.4	231.1

a = Listed in order tested

b = See Table XXXV, Volume II

TABLE B9
WEIGHT MEASUREMENTS^a FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION B^b
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
$N_1 = 4,000$ CYCLES			$N_1 = 20,000$ CYCLES		
BC-25	193.2	193.3	EA-6	235.9	235.5
AB-12	190.5	191.2	ec-27	238.5	237.0
CC-28	190.5	189.8	DA-5	240.8	242.3
AC-25	190.5	190.9	DA-3	235.7	236.6
BC-22	193.2	193.5	EC-23	236.0	233.7
CB-16	190.6	190.7	FA-2	232.4	231.1
$N_2 = 40,000$ CYCLES			$N_2 = 250,000$ CYCLES		
AB-20	190.3	189.5	EC-21	236.7	236.9
CA-3	191.5	190.5	FC-29	239.7	237.2
BB-19	193.5	193.1	DA-8	240.5	239.5
BB-15	192.3	191.0	EA-9	236.7	235.9
CB-13	190.0	190.0	DC-30	233.3	233.6
AA-10	190.9	189.5	FA-7	235.5	233.1
$N_3 = 250,000$ CYCLES			$N_3 = 10^6$		
BA-10	194.0	193.1	EB-16	235.0	-
AC-24	191.8	-	DB-14	235.6	234.5
CB-15	190.2	189.0	FB-13	234.3	232.3
AB-15	191.3	192.3	DB-15	237.4	238.4
CB-11	190.4	-	EC-31	239.6	242.2
BC-31	195.5	195.3	FB-20	233.6	233.9

a = Listed in order tested

b = See Table XXXV, Volume II

TABLE B10
WEIGHT MEASUREMENTS^a FOR SPECIMENS TESTED FOR
RESIDUAL STRENGTH AFTER FATIGUE CYCLING UNDER CONDITION C
TASK III

24-PLY			32-PLY		
Spec. ID	Initial Weight, gms.	Pre-Test Weight, gms.	Spec. ID	Initial Weight, gms.	Pre-Test Weight Gms.
$N_1 = 50$ CYCLES			$N_1 = 1,000$ CYCLES		
AA-3	191.2	191.5	EB-19	235.6	235.2
BB-20	192.8	193.9	FB-15	233.7	233.6
CB-19	191.6	191.8	DB-12	238.5	237.3
BC-28	198.6	198.4	EB-12	237.4	237.8
AC-23	190.5	190.6	FC-21	237.5	238.6
CB-14	190.3	190.7	DC-22	234.8	236.0
$N_2 = 300$ CYCLES			$N_2 = 4,000$ CYCLES		
AB-13	191.6	191.3	DA-1	234.9	235.1
BB-14	197.1	196.8	EC-29	235.4	235.5
CA-5	199.9	200.0	FA-6	234.4	232.3
CC-30	190.1	189.1	FA-5	232.3	232.5
BB-17	197.1	197.4	EC-28	232.8	232.1
AA-5	191.6	191.3	DB-20	236.1	237.0
$N_3 = 1,000$ CYCLES			$N_3 = 8,000$ CYCLES		
CB-20	192.4	192.2	DA-10	240.9	241.5
AA-6	190.7	191.1	EC-27	240.8	242.3
BB-16	197.4	196.5	FC-22	233.1	232.6
AC-30	188.8	188.8	DB-16	238.0	237.1
CB-18	190.0	189.1	EA-5	234.8	233.9
BA-9	191.4	190.0	F-11	230.9	232.6

a = Listed in order tested

b = See Table XXXV, Volume II

APPENDIX C

Static Test Data

TABLE C1
TENSION TEST RESULTS FOR 24-PLY 67% 0° FIBER T300/5208 UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS
TASK II

Specimen ID	Average Area, A Inch ²	Ultimate Load, P _{ult} kips	Ultimate Stress, σ_{ult} ksi	Ultimate Strain, ϵ_{ult} (in./in) mm/mm	Apparent Modulus of Elasticity E _a psi · 10 ⁶	Failure Location Distance from Tab inch
WI-1406-DA	0.1208	19.7	163.3	0.0106	15.1	0
WI-1406-DB	0.1208	18.8	155.8	0.0102	15.0	0
WI-1408-BA	0.1201	20.4	169.7	0.0110	15.1	0
WI-1408-BB	0.1207	19.9	164.9	0.0105	15.2	0
WI-1408-CA	0.1201	20.0	166.1	0.0107	15.1	84
WI-1408-CB	0.1203	18.3	152.1	0.0097	15.6	0
WI-1436-AA	0.1216	19.7	161.6	0.0106	14.7	0
WI-1436-AB	0.1218	18.2	149.4	0.0095	15.0	0
WI-1438-CA	0.1203	18.2	151.3	0.0097	15.3	0
WI-1438-CB	0.1211	20.0	164.9	0.0106	15.3	84
WI-1438-FA	0.1205	20.4	168.9	0.0109	15.0	0
WI-1438-FB	0.1206	20.9	173.3	0.0110	15.2	25
WI-1440-CA	0.1213	21.3	175.6	0.0110	15.8	0
WI-1440-CB	0.1219	19.7	162.0	0.0103	15.5	0
WI-1440-HA	0.1212	20.2	166.3	0.0110	14.7	84
WI-1440-HB	0.1209	19.1	157.6	0.0100	15.1	0
WI-1441-IA	0.1223	20.3	166.0	0.0101	16.1	0
WI-1441-IB	0.1227	20.8	169.5	0.0110	14.8	0
Mean		163.2	1125	0.0105	15.2	105
Std. Dev.		7.5	52	0.0005	0.4	3
Coef. of Var. %		4.6	32	4.8	2.4	17

TABLE C2
TENSION TEST RESULTS FOR 32-PLY QUASI-ISOTROPIC T300/5208 UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS
TASK II

Specimen ID	Average Area, A in ²	in ²	mm ²	Ultimate Load, P _{ult} kip	kN	Ultimate Stress, σ _{ult} ksi	MPa	Ultimate Strain, ε _{ult} in./in. (mm/mm)	Slope Deviation Stress, σ _y ksi	MPa	Slope Deviation Strain, ε _y in./in. (mm/mm)	Initial Apparent Modulus, E ₁ psi·10 ⁶	GPa	Secondary Apparent Modulus, E ₂ psi·10 ⁶	GPa	Failure Location Distance from Tab in	mm
WI-1411-1A	0.1621	105	13.2	58.7	81.4	561	54.8	0.0110	54.8	378	0.0070	7.7	53	6.68	46	1.0	25
WI-1411-1B	0.1618	104	12.5	55.6	77.0	531	51.5	0.0100	51.5	355	0.0066	7.7	53	6.96	48	2.5	64
WI-1411-1A	0.1598	103	12.5	55.6	78.2	539	51.3	0.0105	51.3	354	0.0065	8.0	55	6.83	47	2.3	56
WI-1411-1B	0.1614	104	12.4	55.2	76.8	530	51.1	0.0102	51.1	352	0.0063	7.9	54	6.73	46	0.5	13
WI-1429-1A	0.1618	104	12.3	54.7	75.7	522	51.8	0.0098	51.8	357	0.0064	8.1	56	6.93	48	2.0	51
WI-1429-1B	0.1600	104	11.9	52.9	74.1	511	51.4	0.0094	51.4	354	0.0062	8.3	57	6.78	47	0.3	8
WI-1429-1A	0.1582	102	13.1	58.3	82.8	571	52.1	0.0105	52.1	359	0.0062	8.3	57	7.02	48	1.3	33
WI-1429-1B	0.1587	102	13.4	59.6	84.1	580	48.0	0.0109	48.0	331	0.0058	8.4	58	6.91	48	1.0	25
WI-1431-1A	0.1596	103	12.6	56.0	78.6	542	53.6	0.0102	53.6	370	0.0066	8.1	56	6.81	47	2.5	64
WI-1431-1B	0.1606	104	12.3	54.7	76.3	526	49.0	0.0099	49.0	338	0.0061	8.1	56	7.08	49	0.8	20
WI-1431-1A	0.1595	103	12.3	54.7	77.1	532	52.5	0.0098	52.5	362	0.0064	8.3	57	6.87	47	2.5	64
WI-1431-1B	0.1597	103	12.6	56.0	79.0	545	52.9	0.0104	52.9	365	0.0066	8.2	56	6.66	46	2.0	51
WI-1435-1A	0.1614	104	12.1	53.8	75.0	517	54.2	0.0100	54.2	374	0.0069	7.8	54	6.48	45	0.5	13
WI-1435-1B	0.1610	104	11.8	52.5	73.4	506	49.2	0.0094	49.2	339	0.0061	8.1	56	6.75	47	2.8	71
WI-1435-1A	0.1602	103	12.2	54.3	76.2	525	47.9	0.0095	47.9	330	0.0055	8.6	59	6.84	47	1.0	25
WI-1435-1B	0.1602	103	11.4	50.7	71.2	491	47.9	0.0094	47.9	330	0.0061	7.8	54	6.78	47	1.3	33
WI-1436-1A	0.1596	103	12.2	54.3	76.7	529	50.6	0.0100	50.6	349	0.0063	7.9	55	6.75	47	0.8	20
WI-1436-1B	0.1587	102	13.0	57.8	81.6	583	47.6	0.0104	47.6	328	0.0055	8.8	60	6.85	47	3.5	89
Average																47	
Std. Dev.																1	
Coef. of Var. %																14	

TABLE C3
TENSION TEST RESULTS FOR 24-PLY 67% 0° FIBER T300/5208
UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS - TASK III

Specimen ID	Average Area, A inch ²	Ultimate Load P _{ult} kips	Ultimate Stress σ _{ult} ksi	Ultimate Strain in/in. (mm/mm)	Apparent Modulus E _a psi. 10 ⁶	Failure Location Distance From Tab inch
2WI1477-AA	0.1206	19.6	162.1	0.0112	14.5	2.0
2WI1477-BB	0.1207	19.2	159.1	0.0108	14.7	1.8
2WI1441-AA	0.1197	19.2	160.4	0.0109	15.1	0.0
2WI1441-BB	0.1210	18.9	155.8	0.0108	14.4	2.6
1WI1443-AA	0.1205	19.1	158.1	0.0110	14.4	2.4
1WI1443-BB	0.1220	18.6	152.0	0.0104	14.6	2.0
Mean			157.9	0.0109	14.6	
Standard Deviation			3.6	0.0003	0.3	
Coeff. of Var. %			2.3	2.5	1.8	

TABLE C4
TENSION TEST RESULTS FOR 32-PLY QUASI-ISOTROPIC T300/5208
UNDAMAGED 1-INCH (25 mm) WIDE SPECIMENS - TASK III

Specimen ID	Average Area, A inch ²	mm ²	Ultimate Load P _{ult} kip	KN	Ultimate Stress σ_{ult} ksi	MPa	Ultimate Strain in./in. (mm/mm)	Slope Deviation Stress σ_y ksi	MPa	Slope Deviation Strain, ϵ_y in./in. (mm/mm)	Initial Apparent Modulus E_i psi. 10 ⁴	gpa	Secant Modulus At Failure E_s psi. 10 ⁴	GPa	Failure Location Distance From Tab inch mm
2MI1466-AA	0.1627	105	10.6	47.2	64.8	447	0.0082	37.3	257	0.0042	8.9	61	7.9	55	0.7 18
2MI1466-BB	0.1637	106	11.7	52.0	71.5	493	0.0099	58.6	404	0.0080	7.3	50	7.2	50	0.8 20
1MI1466-AA	0.1627	105	11.7	52.0	71.6	494	0.0090	54.4	375	0.0062	8.8	61	8.0	55	2.2 56
1MI1466-BB	0.1638	106	13.3	59.2	81.2	560	0.0110	36.6	252	0.0042	8.7	60	7.4	51	3.1 79
1MI1478-AA	0.1607	104	12.2	54.3	75.6	521	0.0110	53.4	368	0.0072	7.4	51	6.9	47	0.8 20
1MI1478-BB	0.1627	105	11.3	50.3	69.1	476	0.0090	35.3	243	0.0040	8.2	56	7.7	53	2.6 66
Mean					72.3	498	0.0097	45.9	316	0.0056	8.2	57	7.5	52	
Standard Deviation					5.6	39	0.0012	10.6	73	17.4	0.7	4.8	0.4	2.8	
Coef. of Var. %					7.8	8	11.9	23.1	23	30.9	8.5	9	5.5	6	

TABLE C5a 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II
STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Failure Strain ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E_{sf} , psi x 10 ⁶	Initial Tangent Modulus E_i , psi x 10 ⁶
AB-16	0.368	23.8	64.7	0.0084	7.7	8.6
BB-13	0.365	26.7	73.2	0.0095	7.7	8.9
BC-23	0.365	27.5	75.4	0.0103	7.3	8.7
CC-28	0.365	26.5	72.6	0.0096	7.6	9.3
DA-7	0.359	24.8	69.1	0.0090	7.7	8.9
DC-23	0.362	28.9	79.8	0.0109	7.3	8.9
EA-8	0.362	25.9	71.6	0.0092	7.8	8.8
EB-19	0.362	29.4	81.2	0.0111	7.3	8.9
FA-4	0.365	24.2	66.3	0.0086	7.8	9.2
FC-30	0.359	29.6	82.4	0.0108	7.6	9.1
GA-2	0.362	28.1	78.1	0.0107	7.3	8.7
GB-17	0.365	26.0	71.3	0.0095	7.5	8.8
HA-5	0.362	25.9	71.6	0.0095	7.6	8.9
IA-9	0.361	27.2	75.3	0.0099	7.6	9.2
IC-21	0.359	29.1	81.0	0.0111	7.3	9.0
		Mean	74.2	0.0099	7.5	8.9
		Std. Dev.	5.5	0.0009	0.2	0.2
		Coef. of Var. %	7.3	9.1	2.5	2.3

TABLE C5b 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

STANDARD STRAIN RATE - 0.005 mm/mm/min.							
Specimen ID	Average Gross Area, A mm ²	Failure Load, P _{ult} , kN	Gross Failure Stress σ_{ult} , MPa	Apparent Failure Strain ϵ_f , in./in. in 22.9 mm	Secant Modulus at Failure E _{sf} , GPa	Initial Tangent Modulus E _i , GPa	
AB-16	237	106	446	0.0084	53	60	
BB-13	235	119	505	0.0095	53	62	
BC-23	235	122	520	0.0103	50	60	
CC-28	235	118	501	0.0096	52	65	
DA-7	232	110	476	0.0090	53	62	
DC-23	234	129	550	0.0109	50	62	
EA-8	234	115	494	0.0092	54	61	
EB-19	234	131	560	0.0111	50	62	
FA-4	235	108	457	0.0086	54	64	
FC-30	232	132	568	0.0108	52	63	
GA-2	234	125	538	0.0107	50	60	
GB-17	235	116	492	0.0095	52	61	
HA-5	234	115	494	0.0095	52	62	
IA-9	233	121	519	0.0099	52	64	
IC-21	232	129	558	0.0111	50	63	
		Mean	512	0.0099	52	62	
		Std. Div.	38	0.0009	1	1	
		Coef. of Var. %	7	9.1	3	2	

TABLE C6a 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

HIGH STRAIN RATE - 5 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Initial Tangent Modulus E _i , psi x 10 ⁶
AB-19	0.365	22.7	62.3	0.0073	8.4
DC-25	0.362	24.7	68.1	0.0082	8.7
EA-3	0.362	25.2	69.7	0.0086	8.5
HC-28	0.362	24.9	68.8	0.0082	9.0
IB-11	0.359	24.7	68.8	0.0085	8.6
		Mean	67.5	0.0082	8.7
		Std. Dev.	3.0	0.0005	0.2
		Coef. of Var. %	4.4	6.3	2.5

TABLE C6b 24-PLY DAMAGED HOLE TENSION RESULTS - TASK II

HIGH STRAIN RATE - 5 mm/mm/min.

Specimen ID	Average Gross Area ₂ , A (mm ²)	Failure Load P _{ult} , KN	Gross Failure Stress σ_{ult} , MPa	Apparent Fracture Strain ϵ_f , mm/mm in 228.6 mm	Initial Tangent Modulus E _i , GPa
AB-19	235.5	101.0	429.5	0.0073	58
DC-25	233.5	109.9	469.5	0.0082	60
EA-3	233.5	112.1	480.6	0.0086	59
HC-28	233.5	110.8	474.4	0.0082	62
IB-11	231.6	109.9	474.4	0.0085	59
		Mean	465.4	0.0082	60
		Std. Dev.	21	0.0005	1
		Coef. of Var. %	4	6.3	3

TABLE C7a 32-PLY DAMAGED HOLE TENSION RESULTS - TASK 11
STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E_{sf} , 10 ⁶ psi x 10 ⁶	Initial Tangent Modulus E_i , 10 ⁶ psi x 10 ⁶
JA-8	0.483	21.0	43.5	0.0089	4.9	5.3
JB-17	0.486	20.0	41.2	0.0085	4.8	5.1
KC-25	0.483	20.0	41.4	0.0082	5.0	5.2
KC-26	0.484	18.5	38.2	0.0079	4.8	5.2
LB-13	0.481	19.0	39.5	0.0079	5.0	5.2
MA-3	0.483	19.3	39.9	0.0081	5.0	5.2
MC-30	0.482	20.0	41.5	0.0085	4.9	5.0
NA-7	0.484	18.3	37.7	0.0078	4.9	5.0
NA-9	0.481	19.5	40.5	0.0081	5.0	5.2
PB-11	0.483	20.5	42.4	0.0086	4.9	5.1
PC-24	0.484	19.0	39.3	0.0081	4.8	5.0
QC-26	0.486	19.8	40.7	0.0083	4.9	5.1
RB-12	0.480	20.0	41.6	0.0084	5.0	5.1
SB-12	0.480	18.5	38.5	0.0078	4.9	5.3
SC-29	0.477	19.0	39.8	0.0077	5.2	5.2
Mean						
			40.4	0.0082	4.9	5.1
Std. Dev.			1.6	0.0003	0.1	0.1
Coef. of Var. %			4.0	4.2	2.1	2.0

TABLE C7b 32-PLY DAMAGED HOLE TENSION RESULTS - TASK I1
STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A (mm ²)	Failure Load, P _{ult} , KN	Gross Failure Stress, σ_{ult} , MPa	Apparent Fracture Strain ϵ_f , mm/mm in 228.6 mm	Secant Modulus at Failure E _{sf} , GPa	Initial Tangent Modulus E _i , GPa
JA-8	311.6	93.4	300	0.0089	34	37
JB-17	313.5	89.0	284	0.0085	33	35
KC-25	311.6	89.0	285	0.0082	35	36
KC-26	312.3	82.3	263	0.0079	33	36
LB-13	310.3	84.5	272	0.0079	35	36
MA-3	311.6	85.9	275	0.0081	35	36
MC-30	311.0	89.0	286	0.0085	34	35
NA-7	312.3	81.4	260	0.0078	34	35
NA-9	310.3	86.7	279	0.0081	35	36
PB-11	311.6	91.2	292	0.0086	34	35
PC-24	312.3	84.5	271	0.0081	33	35
QC-26	313.5	88.1	281	0.0083	34	35
RB-12	309.7	89.0	287	0.0084	35	35
SB-12	309.7	82.3	265	0.0078	34	37
SC-29	307.7	84.5	274	0.0077	36	36
		Mean	279	0.0082	34	35
		Std. Dev.	11	0.0003	14	1
		Coef. of Var.	4	0.003	2	2

TABLE C 8a
32-PLY DAMAGED HOLE TENSION RESULTS - TASK II
HIGH STRAIN RATE - 2 in./in./min

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E_{sf} , 10 ⁶ psi	Initial Tangent Modulus E_t , 10 ⁶ psi
JC-29	0.485	18.4	38.1	0.0079	4.8	5.3
NC-29	0.474	19.1	40.3	0.0085	4.7	5.3
PA-8	0.483	22.3	46.2	0.0105	4.4	5.0
QB-19	0.485	18.7	38.5	0.0080	4.8	5.2
SC-21	0.472	17.4	36.8	0.0074	5.0	5.5
Mean						
			40.0	0.0085	4.7	5.3
Std. Dev.						
			13.4	12		0.2
Coef. of Var. %						
			9.2	14.2		3.5

TABLE C 8b
32-FLY DAMAGED HOLE TENSION RESULTS - TASK 11
HIGH STRAIN RATE - 2 mm/mm/min.

Specimen ID	Average Gross Area, A (mm ²)	Failure Load, P _{ult} , (KN)	Gross Failure Stress, σ_{ult} , (MPa)	Apparent Fracture Strain, ϵ_f , mm/mm in 229 mm	Secant Modulus At Failure E _{sf} , (GPa)	Initial Tangent Modulus E _i , (GPa)
JC-29	313	81	263	0.0079	33	37
NC-29	306	85	278	0.0085	32	37
PA-8	312	99	319	0.0105	30	34
QB-19	313	83	265	0.0080	33	36
SC-21	305	77	254	0.0074	34	38
Mean			276	0.0085	32	37
Std. Dev.			23	12	1	1
Coef. of Var. %			9.2	14.2	5	4

TABLE C9a 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_f , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E _{sf} , 10 ⁶ psi x 10 ⁶	Secant Modulus at 30 ksi E _{s30} , 10 ⁶ psi x 10 ⁶
AA-4	0.365	16.1	44.1	0.0055	8.1	8.6
AA-6	0.362	16.6	45.9	0.0056	8.2	8.9
AB-18	0.365	16.4	45.0	0.0056	8.1	8.5
BB-18	0.362	17.1	47.3	0.0058	8.2	8.6
CA-8	0.365	15.7	43.0	0.0051	8.5	8.6
CC-21	0.365	15.8	43.3	0.0054	8.1	8.9
DB-11	0.359	14.8	41.2	0.0051	8.1	8.9
DB-17	0.362	17.2	47.5	0.0060	8.0	8.6
EC-22	0.362	18.1	50.0	0.0062	8.1	8.7
FB-14	0.362	16.0	44.2	0.0054	8.2	8.7
GB-19	0.362	17.1	47.3	0.0058	8.2	8.6
HB-13	0.362	14.5	40.0	0.0048	8.4	8.5
HB-18	0.361	14.6	40.4	0.0047	8.6	8.9
IA-3	0.365	15.8	43.3	0.0054	8.1	8.7
IC-29	0.365	15.9	43.9	0.0054	8.2	8.6
	Mean		44.4	0.0054	8.2	8.7
	Std. Dev.		2.8	0.0004	0.2	0.1
	Coef. of Var. %		6.3	7.6	2.0	1.7

TABLE C9b 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK 11
STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A mm ²	Failure Load, P _{ult} , kN	Gross Failure Stress, σ_f , MPa	Apparent Fracture Strain, ϵ_f , in./in. in 22.9 mm	Secant Modulus at Failure E _{sf} , GPa	Secant Modulus at 207 MPa E _{s207} , GPa
AA-4	235	71.6	304	0.0055	56	59
AA-6	234	73.8	316	0.0056	57	61
AB-18	235	73.0	310	0.0056	56	59
BB-18	234	76.1	326	0.0058	57	59
CA-8	235	69.8	296	0.0051	59	59
CC-21	235	70.3	299	0.0054	56	61
DB-11	232	65.8	284	0.0051	56	61
DB-17	234	76.5	328	0.0060	55	59
EC-22	234	80.5	345	0.0062	56	60
FB-14	234	71.1	305	0.0054	57	60
GB-19	234	76.1	326	0.0058	57	59
HB-13	234	64.5	276	0.0048	58	59
HB-18	233	64.9	279	0.0047	59	61
IA-3	235	70.3	299	0.0054	56	60
IC-29	235	70.7	303	0.0054	57	59
		Mean	306	0.0054	57	60
		Std. Dev.	19	0.0004	1	1
		Coef. of Var. %	6.3	7.6	2	2

TABLE C10a 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II
HIGH STRAIN RATE - 5 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Initial Tangent Modulus E _i , 10 ⁶ psi
EC-23	0.362	13.0	36.0	0.0045	8.6
FB-13	0.362	13.3	36.8	0.0046	9.2
FC-21	0.359	13.4	37.5	0.0047	8.6
GB-14	0.362	12.0	33.1	0.0044	8.2
GC-30	0.365	15.0	41.1	0.0052	8.7
Mean					8.7
Std. Dev.					0.4
Coef. of Var. %					4.1
					6.7

TABLE C10b 24-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II

HIGH STRAIN RATE - 5 mm/mm/min.

Specimen ID	Average Gross Area, A (mm ²)	Failure Load P _{ult} , kN	Gross Failure Stress σ_{ult} , MPa	Apparent Fracture Strain ϵ_f , mm/mm in 228.6 mm	Initial Tangent Modulus E _i , GPa
EC-23	233.5	57.8	248	0.0045	59
FB-13	233.5	59.2	254	0.0046	64
FC-21	231.6	59.6	259	0.0047	59
GB-14	233.5	53.4	226	0.0044	57
GC-30	235.5	66.7	283	0.0052	60
		Mean	254	0.0047	60
		Std. Dev.	20	0.0003	3
		Coef. of Var. %	8	7	4

TABLE C11a 32-PLY DAMAGED HOLE COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK 11

STANDARD STRAIN RATE - 0.005 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E_{sf} , 10^6 psi $\times 10^6$	Initial Tangent Modulus E_i , 10^6 psi $\times 10^6$
JC-21	0.481	16.5	34.3	0.0073	4.7	5.2
JC-26	0.487	17.5	36.0	0.0077	4.7	5.0
KB-13	0.485	16.8	34.6	0.0075	4.6	5.1
LA-8	0.482	17.5	36.3	0.0076	4.8	5.2
LC-29	0.483	17.0	35.2	0.0074	4.7	5.1
MA-7	0.483	15.8	32.6	0.0069	4.7	5.1
MC-24	0.482	16.0	33.2	0.0070	4.8	5.2
NB-11	0.481	17.5	36.3	0.0077	4.7	5.3
PC-18	0.483	16.3	33.6	0.0070	4.8	5.2
QA-5	0.486	15.6	32.2	0.0068	4.8	5.2
QB-16	0.488	17.0	34.8	0.0073	4.8	5.1
RA-4	0.483	15.4	31.9	0.0066	4.9	5.0
RB-18	0.480					
RC-30	0.489	17.0	35.4	0.0074	4.8	5.3
S-15	0.483	15.5	32.1	0.0066	4.8	5.0
Mean						
Std. Dev.						
Coef. of Var. %						
			34.2	0.0072	4.8	5.1
			1.5	0.0004	0.1	0.1
			4.5	5.3	1.6	2.0

TABLE C11b 32-PLY DAMAGED HOLF COMPRESSION RESULTS (WITH FATIGUE SUPPORT) - TASK II
STANDARD STRAIN RATE - 0.005 mm/mm/min.

Specimen ID	Average Gross Area, A (mm ²)	Failure Load, P _{ult} , KN	Gross Failure Stress, σ_{ult} , MPa	Apparent Fracture Strain ϵ_f , mm/mm in 228.6 mm	Secant Modulus at Failure E _{sf} , GPa	Initial Tangent Modulus E _i , GPa
JC-21	310.3	73.4	237	0.0073	32	36
JC-26	314.2	77.8	248	0.0077	32	35
KB-13	312.9	74.7	239	0.0075	32	35
LA-8	311.0	77.8	250	0.0076	33	36
LC-29	311.6	75.6	243	0.0074	32	35
MA-7	311.6	70.3	225	0.0069	32	35
MC-24	311.0	71.2	230	0.0070	33	36
NB-11	310.3	77.8	250	0.0077	32	37
PC-18	311.6	72.5	232	0.0070	33	36
QA-5	313.5	69.4	222	0.0068	33	36
QB-16	314.8	75.6	240	0.0073	33	35
RA-4	311.6	68.5	220	0.0066	34	35
RB-18	309.7					
RC-30	315.5	75.6	244	0.0074	33	37
S-15	311.6	68.9	221	0.0066	33	35
Mean						
Std. Dev.						
Coef. of Var. %						
			236	0.0072	33	35
		10	10	0.0004	1	1
		5	5	5	2	2

TABLE C12a
 32-PLY DAMAGED HOLE COMPRESSION RESULTS - TASK II
 (WITH FATIGUE SUPPORT)
 HIGH STRAIN RATE - 0.5 in./in./min.

Specimen ID	Average Gross Area, A (in. ²)	Failure Load, P _{ult} , kip	Gross Failure Stress, σ_{ult} , ksi	Apparent Fracture Strain, ϵ_f , in./in. in 9 in.	Secant Modulus At Failure E_{sf} , psi x 10 ⁶	Initial Tangent Modulus E_t , psi x 10 ⁶
KA-6	0.486	16.3	33.5	0.0072	4.7	5.3
KA-8	0.486	13.9	28.6	0.0057	5.0	5.0
NB-15	0.486	11.1	22.9	0.0046	5.0	5.0
RA-3	0.482	13.3	27.6	0.0066	4.2	4.8
RC-26	0.483	16.3	33.8	0.0073	4.6	5.2
Mean						
Std. Dev.			29.3	0.0063	4.7	5.1
Coef. of Var. %			4.5	0.0010	0.3	0.2
			15.5	18.1	7.1	3.9

TABLE C12b
32-PLY DAMAGED HOLE COMPRESSION RESULTS - TASK II
(WITH FATIGUE SUPPORT)

HIGH STRAIN RATE - 0.5 mm/mm/min.

Specimen ID	Average Gross Area, A (mm ²)	Failure Load, P _{ult.} (KN)	Gross Failure Stress, $\sigma_{ult.}$ (MPa)	Apparent Fracture Strain, ϵ_f , mm/mm in 229 mm	Secant Modulus At Failure E _{sf.} (GPa)	Initial Tangent Modulus E _{i.} (GPa)
KA-6	314	73	231	0.0072	32	37
KA-8	314	62	197	0.0057	34	34
NB-15	314	49	158	0.0046	34	34
RA-3	311	59	190	0.0066	29	33
RC-26	312	73	233	0.0073	32	36
Mean						
Std. Dev.			202	0.0063	32	35
Coef. of Var. %			31	0.0011	2	1
			16	18.1	7	4

TABLE C13a

STATIC TENSION TEST
RESULTS - TASK III

Specimen ID	Average Gross Area, A in. 2	Failure Load P_{ult} , kips	Gross Failure Stress σ_{ult} , ksi	Apparent Strain at Failure ϵ_f , in./in.	Secant Modulus at Failure E_f , $\text{psi} \times 10^6$	Initial Tangent Modulus E_i , $\text{psi} \times 10^6$
24 PLY LAMINATE						
AB-18	0.3628	24.6	67.8	0.0092	7.4	8.8
BA-2	0.3652	25.8	70.9	0.0099	7.2	8.7
CC-22	0.3577	26.4	73.8	0.0103	7.2	8.9
Mean			70.8	0.0098	7.2	8.8
Std. Dev.			3.0	0.0006	0.1	0.1
Coeff. of Var. %			4.2	5.7	1.6	1.3
32 PLY LAMINATE						
DC-24	0.4871	18.4	37.8	0.0090	4.2	5.0
EC-26	0.4862	20.2	41.5	0.0092	4.5	5.3
FB-12	0.4791	19.5	40.7	0.0083	4.9	5.0
Mean			40.0	0.0088	4.5	5.1
Std. Dev.			1.9	0.0005	0.4	0.2
Coeff. of Var. %			4.9	5.3	7.7	3.7

TABLE C13b
STATIC TENSION TEST
RESULTS - TASK III

Specimen ID	Average Gross Area, mm^2	Failure Load P_{ult} , KN	Gross Failure Stress σ_{ult} , MPa	Apparent Failure Strain ϵ_f , mm/mm	Secant Modulus at Failure E_{sf} , GPa	Initial Tangent Modulus E_i , GPa
24 PLY LAMINATE						
AB-18	234	109.4	467	0.0092	51	61
BA-2	236	114.8	489	0.0099	49	60
CC-22	231	117.4	509	0.0103	49	62
Mean			488	0.0098	50	62
Std. Dev.			20.7	0.0006	0.8	0.8
Coeff. of Var. %			4.2	5.7	1.6	1.3
32 PLY LAMINATE						
DC-24	314	81.8	261	0.0090	29.	34
EC-26	314	89.9	286	0.0092	31.	37
FB-12	309	86.7	281	0.0083	34	34
Mean			275	0.0088	31	35
Std. Dev.			13.1	0.0005	2	1
Coeff. of Var. %			4.9	5.3	8	4

TABLE C14a
 STATIC COMPRESSION TEST
 RESULTS WITH FATIGUE SUPPORT - TASK III

Specimen ID	Average Gross Area, A ₂ in. ²	Failure Load P _{ult} , kips	Gross Failure Stress σ_{ult} , ksi	Apparent Strain at Failure ϵ_f in./in. in 9 in.	Secant Modulus at Failure E _f x 10 ⁶ psi x 10 ⁶	Secant Modulus E _a psi x 10 ⁶
24 PLY LAMINATE						
AC-28	0.3672	17.8	48.3	0.0077	6.3	8.0
BC-30	0.3601	14.5	40.3	0.0056	7.2	8.3
CC-25	0.3645	18.5	50.8	0.0086	5.6	8.0
Mean			46.5	0.0073	6.4	8.1
Std. Dev.			5.5	0.0015	0.8	0.2
Coeff. of Var. %			11.8	21.1	12.6	2.2
32 PLY LAMINATE						
DA-2	0.4898	17.5	35.7	0.0094	3.8	4.6
EB-14	0.4884	17.2	35.3	0.0090	3.9	4.6
FB-17	0.4856	17.5	36.0	0.0096	3.8	4.7
Mean			35.7	0.0093	3.8	4.6
Std. Dev.			0.4	0.0003	0.1	0.1
Coeff. of Var. %			1.0	3.3	2.3	1.3

a = Secant Modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate

TABLE C14b
 STATIC COMPRESSION TEST
 RESULTS WITH FATIGUE SUPPORT - TASK III

Specimen ID	Average Gross Area, A mm ²	Failure Load P_{ult} , KN	Gross Failure Stress σ_{ult} , MPa	Apparent Failure Strain ϵ_f mm/mm	Secant Modulus at Failure E_{sf} , GPa	Secant Modulus E_s^a GPa
24 PLY LAMINATE						
AC-28	237	79.2	333	0.0077	43	55
BC-30	232	64.5	278	0.0056	50	57
CC-25	235	82.3	350	0.0086	39	55
Mean			321	0.0073	44	56
Std. Dev.			37.9	0.0015	6	1
Coeff. of Var. %			11.8	21.1	13	2
32 PLY LAMINATE						
DA-2	316	77.8	246	0.0094	26	31
EB-14	315	77.0	243	0.0090	27	31
FB-17	313	77.8	248	0.0096	26	32
Mean			246	0.0093	26	32
Std. Dev.			2.8	0.0003	1	1
Coeff. of Var. %			1.0	3.3	2	1

a = Secant modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate

TABLE C15a
 STATIC COMPRESSION TEST
 RESULTS WITH 4-BAR COLUMN BUCKLING SUPPORT - TASK 111

Specimen ID	Average Gross Area, A in. ²	Failure Load P_{ult} , kips	Failure Stress σ_{ult} , ksi	Apparent Strain at Failure ϵ_f in./in.	Secant Modulus at Failure E_f $\times 10^6$ psi	Secant Modulus E_s $\times 10^6$ psi
24 PLY LAMINATE						
AB-17	0.3672	14.5	39.5	0.0051	7.8	8.9
BC-26	0.3648	16.5	45.2	0.0061	7.4	8.8
CB-17	0.3648	15.0	41.1	0.0056	7.3	8.7
Mean			41.9	0.0056	7.5	8.8
Std. Dev.			2.9	0.0005	0.2	0.1
Coeff. of Var. %			7.0	8.9	2.9	1.1
32 PLY LAMINATE						
DA-4	0.4898	15.0	30.6	0.0065	4.7	4.9
EA-2	0.4868	20.0	41.1	0.0061	4.5	5.00
FB-16	0.4870	16.3	33.4	0.0071	4.7	4.9
Mean			35.0	0.0076	4.6	4.9
Std. Dev.			5.4	0.0014	0.1	0.1
Coeff. of Var. %			15.5	18.0	2.3	1.4

a = Secant modulus E_{s30} at 30 ksi for 24-ply laminate and E_{s20} at 20 ksi for 32-ply laminate.

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F/S 11/4

ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC-ETC(U)

JUL 81 K M LAURAITIS, J T RYDER, D E PETTIT

F33615-77-C-3004

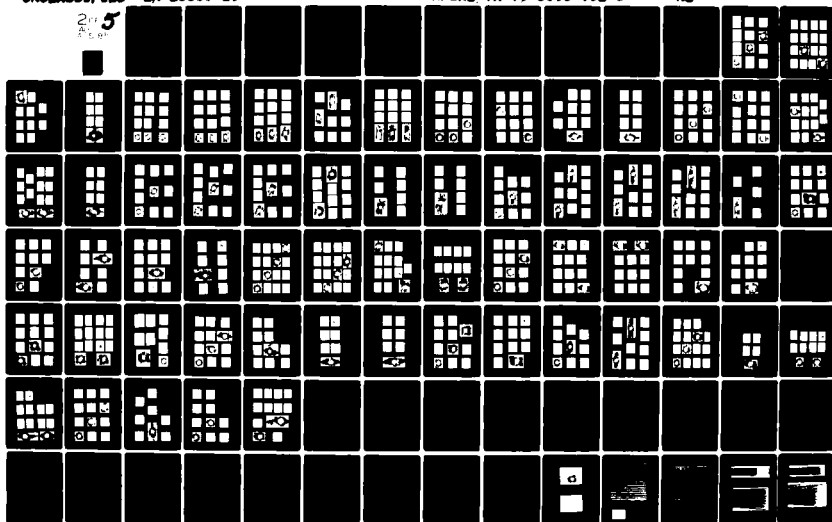
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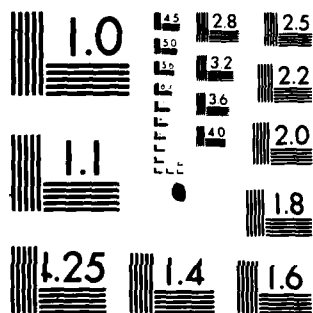
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MICROCOPY RESOLUTION TEST CHART
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TABLE C15b
 STATIC COMPRESSION TEST
 RESULTS WITH 4-BAR COLUMN BUCKLING SUPPORT - TASK III

Specimen ID	Average Gross Area, A mm ²	Failure Load P _{ult} , KN	Gross Failure Stress P _{ult} , MPa	Apparent Failure Strain ϵ_f , mm/mm	Secant Modulus at Failure E _{sf} , GPa	Secant Modulus E _a , GPa
24 PLY LAMINATE						
AB-17	237	64.5	272	0.0051	53	61
BC-26	235	73.4	312	0.0061	51	61
CB-17	235	66.7	283	0.0056	51	60
Mean			289	0.0056	52	61
Std. Dev.			20	0.0005	2	1
Coeff. of Var. %			7	8.9	3	1
32 PLY LAMINATE						
DA-4	316	66.7	211	0.0065	33	34
EA-2	314	89.0	283	0.0091	31.2	35
FB-16	314	72.7	230	0.0071	32.4	34
Mean			241	0.0076	32	34
Std. Dev.			37	0.0014	1	1
Coeff. of Var. %			16	18.0	2	1

a = Secant modulus E_s 30 at 30 ksi for 24-ply laminate and E_s 20 at 20 ksi for 32-ply laminate.

TABLE C16 a
24-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in. ²	Failure Load kip P _{ult}	Gross Failure Stress, ksi σ _{ult}	Apparent Failure Strain ε _f , in./in. in 9 in.	Secant Modulus at Failure E _s , 10 ⁶ psi X 10 ⁶	Initial Tangent Modulus E _t , 10 ⁶ psi X 10 ⁶
4000	AB-13	0.365	28.0	76.7	0.0100	7.7	8.6
	BA-9	0.362	29.9	82.7	0.0106	7.8	8.9
	CC-23	0.362	28.6	78.7	0.0107	7.3	8.7
	EA-7	0.362	27.5	76.0	0.0097	7.8	8.8
	EC-27	0.365	29.5	80.8	0.0095	8.5	9.4
	FC-25	0.365	28.2	77.4	0.0101	7.7	9.2
	GB-16	0.363	30.1	83.0	0.0115	7.2	8.9
	HC-24	0.365	29.9	81.9	0.0115	7.1	8.6
	IA-1	0.360	27.2	75.5	0.0100	7.6	9.1
	AA-7	0.363	28.5	78.4	0.0098	8.0	9.0
8000	EC-30	0.362	31.8	87.7	0.0117	7.5	8.8
	CB-16	0.360	29.5	82.0	0.0111	7.4	8.8
	DC-29	0.362	31.5	86.9	0.0113	7.7	8.8
	EC-24	0.366	29.2	79.6	0.0100	8.0	9.4
	FB-11	0.368	29.2	79.4	0.0108	7.3	8.7
	FC-26	0.363	26.2	72.3	0.0092	7.9	8.8
	GC-22	0.362	29.3	81.0	0.0106	7.7	9.0
	IB-15	0.360	29.5	81.9	0.0112	7.3	8.8
	AA-5	0.368	30.0	81.5	0.0114	7.2	8.6
	AC-27	0.366	29.5	80.6	0.0111	7.8	8.6
12000	BC-21	0.365	31.0	85.0	0.0116	7.3	8.7
	CB-14	0.363	30.0	82.6	0.0112	7.4	9.0
	DA-10	0.342	31.5	92.2	0.0126	7.3	9.1
	DB-15	0.365	31.3	85.6	0.0129	6.6	8.3
	GB-18	0.360	29.8	82.6	0.0106	7.8	8.9
	IA-2	0.362	29.0	80.0	0.0108	7.4	8.9
	AC-25	0.367	30.7	83.7	0.0113	7.4	8.6
	CB-17	0.365	32.6	89.4	0.0122	7.3	9.0
	FB-15	0.365	30.3	83.0	0.0111	7.5	8.6
	GC-24	0.360	30.0	83.3	0.0112	7.5	8.7
20000	GC-25	0.362	28.8	79.4	0.0107	7.4	8.9
	EC-25	0.364	32.4	89.1	0.0118	7.6	8.7
	CB-19	0.364	31.5	86.5	0.0107	8.1	9.1
	FC-27	0.366	32.4	88.4	0.0111	8.0	9.1
	GA-9	0.359	31.9	88.8	0.0116	7.7	9.6
	HC-30	0.362	30.1	83.3	0.0107	7.8	8.9

TABLE C16b
24-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm ²	Failure Load, P _{ult} , kN	Gross Failure Stress, σ _{ult} , MPa	Apparent Failure Strain ε _f , mm/mm in 229 mm	Secant Modulus at Failure E _s , GPa	Initial Tangent Modulus E _t , GPa
4000	AB-13	235	125	529	0.0100	53	59
	BA-9	234	133	570	0.0106	54	61
	CC-23	234	127	543	0.0107	50	60
	EA-7	234	122	524	0.0097	54	61
	EC-27	235	131	557	0.0095	59	65
	FC-25	235	125	534	0.0101	53	63
	GB-16	234	134	572	0.0115	50	61
	HC-24	235	133	565	0.0115	49	59
	IA-1	232	121	521	0.0100	52	63
	AA-7	234	127	541	0.0098	55	62
	BC-30	234	141	605	0.0117	52	61
	CB-16	232	131	565	0.0111	51	61
8000	DC-29	234	140	599	0.0113	53	61
	EC-24	236	130	549	0.0100	55	65
	FB-11	237	130	547	0.0108	50	60
	FC-26	234	117	498	0.0092	54	61
	GC-22	234	130	558	0.0106	53	62
	IR-15	232	131	565	0.0112	50	61
	AA-5	237	133	562	0.0114	50	59
	AC-27	236	131	556	0.0111	54	59
	BC-21	235	138	586	0.0116	50	60
	CB-14	234	133	570	0.0112	51	62
	DA-10	221	140	636	0.0126	50	63
	DB-15	235	139	590	0.0129	46	57
12000	GB-18	232	133	570	0.0106	54	61
	IA-2	234	129	552	0.0108	51	61
	AC-25	237	137	577	0.0113	51	59
	CB-17	235	145	616	0.0122	50	62
	FB-15	235	135	572	0.0111	52	59
	GC-24	232	133	574	0.0112	52	60
	CC-25	234	128	547	0.0107	51	61
	EC-25	235	144	614	0.0118	52	60
	CB-19	235	140	596	0.0107	56	63
	FC-27	236	144	609	0.0111	55	63
	GA-9	232	142	612	0.0116	53	66
	HC-30	234	134	574	0.0107	54	61
20000							
40000							

TABLE C17a
24-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II
(With Fatigue Supports)

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in. ²	Failure Load, kip ult.	Gross Failure Stress, σ_f , ksi	Apparent Fracture Strain ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E _f , psi X 10 ⁶	Secant Modulus at 30 ksi E ₃₀ , psi X 10 ⁶
4000	AB-14	0.368	17.5	47.6	0.0064	7.5	8.3
	AC-29	0.366	16.5	45.1	0.0057	7.9	8.5
	BA-1	0.357	16.0	44.8	0.0057	7.9	8.6
	DC-22	0.362	18.0	50.0	0.0064	7.8	8.6
	EC-25	0.362	15.5	42.9	0.0055	7.8	8.5
	FB-19	0.364	17.3	47.4	0.0062	7.7	8.6
	FC-24	0.363	15.8	43.4	0.0054	8.0	8.4
	GA-4	0.362	16.8	46.3	0.0060	7.8	8.3
	HA-2	0.363	14.0	38.5	0.0050	7.7	8.3
	HA-7	0.361	19.5	54.0	0.0072	7.5	8.6
8000	AC-24	0.365	16.6	45.4	0.0057	8.0	8.4
	CB-12	0.361	17.3	47.9	0.0060	8.0	8.9
	DA-5	0.362	15.4	42.2	0.0053	8.0	8.5
	DB-18	0.361	17.5	48.5	0.0059	8.2	8.9
	EA-5	0.362	14.6	40.3	0.0051	7.8	8.3
	EC-29	0.363	17.6	48.5	0.0061	7.9	8.9
	GA-6	0.363	17.1	47.1	0.0061	7.7	8.2
	HB-16	0.365	15.7	42.9	0.0056	7.7	8.3
	IC-27	0.364	16.4	45.0	0.0059	7.6	8.2
	BB-19	0.363	17.8	49.0	0.0065	7.5	8.2
12000	CA-2	0.359	19.5	54.3	0.0068	8.0	8.9
	FA-1	0.359	16.3	45.2	0.0058	7.8	8.6
	GA-5	0.361	17.5	48.4	0.0065	7.5	8.3
	HA-6	0.363	19.3	53.0	0.0072	7.4	8.4
	HC-21	0.357	16.0	44.8	0.0059	7.6	8.3
	IA-6	0.364	18.3	50.1	0.0066	7.6	8.6
	AA-3	0.365	16.8	46.2	0.0058	8.0	8.6
	BB-14	0.366	16.3	44.7	0.0056	7.9	8.6
	DB-14	0.366	16.4	44.9	0.0058	7.7	8.3
	FA-2	0.364	14.4	39.4	0.0050	7.9	8.4
20000	FC-29	0.363	18.6	51.3	0.0061	8.4	8.8
	AC-26	0.370	17.3	46.6	0.0058	8.0	8.6
	CC-24	0.363	19.8	54.5	0.0068	8.0	8.9
	CC-27	0.363	17.7	48.7	0.0063	7.8	8.8
	EA-9	0.364	14.9	40.9	0.0049	8.4	8.8
	IB-16	0.363	17.5	48.2	0.0061	7.9	8.7
40000							

TABLE C17b

24-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II
(With Fatigue Supports)

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm ²	Failure Load KN ult.	Gross Failure Stress σ_f , MPa	Apparent Fracture Strain ϵ_f , mm/mm in 229 mm	Secant Modulus at Failure E_{sf} , GPa	Secant Modulus at 30 ksi E_{s30} , GPa
4000	AB-14	237	77.8	328	0.0064	52	57
	AC-29	236	73.4	311	0.0057	54	59
	BA-1	230	71.2	309	0.0057	54	59
	DC-22	234	80.1	345	0.0064	54	59
	EC-25	234	68.9	296	0.0055	54	59
	FB-19	235	77.0	327	0.0062	53	59
	FC-24	234	70.3	299	0.0054	55	58
	GA-4	234	74.7	319	0.0060	54	57
	HA-2	234	62.3	265	0.0050	53	57
	HA-7	233	86.7	372	0.0072	52	59
	AC-24	235	73.8	313	0.0057	55	58
	CB-12	233	77.0	330	0.0060	55	61
	DA-5	234	68.5	291	0.0053	55	59
	DB-18	233	77.8	334	0.0059	57	61
	EA-5	234	64.9	278	0.0051	54	57
	EC-29	234	78.3	334	0.0061	54	61
10000	GA-6	234	76.1	325	0.0061	53	57
	HB-16	235	69.8	296	0.0056	53	57
	IC-27	235	73.0	310	0.0059	52	57
	BB-19	234	79.2	338	0.0065	52	57
	CA-2	232	86.7	374	0.0068	55	61
	FA-1	232	72.5	312	0.0058	54	59
	GA-5	233	77.8	334	0.0065	52	57
	HA-6	234	85.9	365	0.0072	51	58
	HC-21	230	71.2	309	0.0059	52	57
	IA-6	235	81.4	345	0.0066	52	59
	AA-3	235	74.7	319	0.0058	53	59
	BB-14	236	72.5	308	0.0056	54	59
	DB-14	236	73.0	310	0.0058	53	57
	FA-2	235	64.1	272	0.0050	54	58
	FC-29	234	82.7	354	0.0061	58	61
	AC-26	239	77.0	321	0.0058	55	59
40000	CC-24	234	88.1	376	0.0068	55	61
	CC-27	234	78.7	336	0.0063	54	61
	EA-9	235	66.3	282	0.0049	58	61
	IB-16	234	77.8	332	0.0061	54	60

TABLE C18a

32-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A_0 in.	Failure Load P_{ult} , kip	Gross Failure Stress σ_{ult} , ksi	Apparent Failure Strain ϵ_f , in./in. in 9 in.	Secant Modulus at Failure E_f , $\times 10^6$ psi	Initial Tangent Modulus E_i , $\times 10^6$ psi
1,000	JB-16	0.4853	20.6	42.4	0.0097	4.37	4.74
	JC-22	0.4832	20.7	42.8	0.0098	4.37	4.76
	KA-9	0.4856	21.9	45.0	0.0104	4.33	4.90
	KB-18	0.4825	20.0	41.4	0.0091	4.55	5.02
	LA-3	0.4859	21.1	43.3	0.0100	4.33	4.90
	NC-28	0.4830	21.1	43.6	0.0102	4.27	4.89
	NC-30	0.4840	20.1	41.4	0.0092	4.50	4.88
	PA-9	0.4850	20.7	42.7	0.0096	4.45	4.80
	QB-17	0.4870	20.8	42.7	0.0096	4.45	4.76
	RA-2	0.4832	21.1	43.7	0.0094	4.65	5.05
	JA-4	0.4820	20.5	42.5	0.0090	4.72	4.94
	KB-16	0.4812	21.0	43.6	0.0100	4.36	4.86
	KC-28	0.4817	21.4	44.4	0.0090	4.93	5.32
	LA-2	0.4847	20.8	42.8	0.0095	4.51	4.83
	MB-16	0.4842	23.5	48.5	0.0103	4.71	5.74
5,000	NC-22	0.4825	22.8	47.2	0.0100	4.72	5.18
	NC-26	0.4860	22.4	46.0	0.0094	4.89	5.42
	QA-1	0.4877	20.8	42.5	0.0090	4.72	5.13
	QA-9	0.4845	19.8	40.8	0.0088	4.64	4.91
	SB-13	0.4816	20.2	42.0	0.0088	4.77	5.02
	KA-7	0.4860	21.4	43.9	0.0094	4.67	4.98
	LA-7	0.4831	20.8	43.0	0.0088	4.89	5.18
	LC-27	0.4822	20.0	41.6	0.0086	4.84	5.18
	MC-29	0.4679	22.0	47.0	0.0094	5.00	5.23
	NB-16	0.4869	21.3	43.7	0.0091	4.80	5.13
	PA-1	0.4778	22.2	46.6	0.0095	4.91	4.98
	PA-4	0.4786	20.7	43.3	0.0089	4.87	4.97
	QB-12	0.4860	23.3	47.9	0.0099	4.84	5.14
	RB-17	0.4820	20.6	42.8	0.0087	4.92	5.05
	SA-5	0.4799	21.1	44.0	0.0088	5.00	5.37
20,000	JB-15	0.4838	21.5	44.4	0.0094	4.72	5.17
	KB-12	0.4868	20.3	41.7	0.0087	4.79	5.34
	LA-4	0.4824	21.6	44.9	0.0093	4.83	5.18
	LA-5	0.4857	22.0	45.3	0.0091	4.98	5.15
	MB-13	0.4839	20.9	43.2	0.0092	4.70	5.03
	MB-18	0.4833	21.3	44.1	0.0089	4.96	5.17
	NB-17	0.4856	21.2	43.8	0.0092	4.76	4.90
	QC-30	0.4843	21.2	43.7	0.0091	4.80	5.03
	RC-24	0.4832	20.9	43.2	0.0092	4.70	4.93
	SC-23	0.4783	20.7	43.3	0.0089	4.87	5.09
	JC-23	0.4825	21.9	45.4	0.0098	4.63	4.94
	KA-5	0.4852	22.2	45.8	0.0099	4.63	4.91
	KB-14	0.4838	21.8	45.2	0.0098	4.61	4.92
	MA-4	0.4814	20.4	42.2	0.0096	4.39	4.71
	NB-14	0.4857	21.9	45.1	0.0094	4.80	5.42
	PB-12	0.4816	21.8	45.3	0.0098	4.62	4.86
28,000	PB-13	0.4839	20.2	41.7	0.0089	4.69	4.92
	QC-31	0.4787	23.3	48.7	0.0101	4.82	5.44
	RA-5	0.4826	21.0	43.4	0.0089	4.88	5.18
	SB-18	0.4806	21.8	45.4	0.0097	4.68	4.95

TABLE C18f
32-PLY DAMAGED HOLE TENSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm ²	Failure Load P _{ult} , kN	Gross Failure Stress, σ_{ult} , MPa	Apparent Failure Strain ϵ_f , mm/mm in 228.6 mm	Secant Modulus at Failure E_{sf} , GPa	Initial Tangent Modulus E_i , GPa
1,000	JB-15	313	91.6	292	0.0097	30.1	32.7
	JC-22	312	92.1	295	0.0098	30.1	32.8
	KA-9	313	97.2	310	0.0104	29.8	33.8
	KB-18	311	89.0	285	0.0091	31.4	34.6
	LA-3	314	93.9	298	0.0100	29.8	33.8
	NC-28	312	93.9	301	0.0102	29.4	33.7
	NC-30	312	89.4	285	0.0092	31.0	33.7
	PA-9	313	92.1	294	0.0096	30.7	33.1
	QB-17	314	92.5	294	0.0096	30.7	32.8
	RA-2	312	93.9	301	0.0094	32.1	34.8
	JA-4	311	91.2	293	0.0090	32.5	34.1
	KB-16	310	93.4	301	0.0100	30.1	33.5
	KC-28	311	95.2	306	0.0090	34.0	36.7
	LA-2	313	92.5	295	0.0095	31.1	33.3
5,000	MB-16	312	104.5	334	0.0103	32.5	39.6
	NC-22	311	101.4	325	0.0100	32.5	35.7
	NC-26	314	99.6	317	0.0094	33.7	37.4
	QA-1	315	92.5	293	0.0090	32.5	35.4
	QA-9	313	88.1	281	0.0088	32.0	33.8
	SB-13	311	89.8	290	0.0088	32.9	34.6
	KA-7	314	95.2	303	0.0094	32.2	34.3
	LA-7	312	92.5	296	0.0088	33.7	35.7
	LC-27	311	89.0	287	0.0086	33.4	33.7
	MC-29	302	97.9	324	0.0094	34.5	36.1
	NB-16	314	94.8	301	0.0091	33.1	33.4
	PA-1	308	98.8	321	0.0095	33.8	34.3
	PA-4	309	92.1	298	0.0089	33.6	34.3
	QB-12	314	103.6	330	0.0099	33.4	35.4
20,000	RB-17	311	91.6	295	0.0087	33.9	34.8
	SA-5	310	93.9	303	0.0088	34.5	37.0
	JB-15	312	95.6	306	0.0094	32.5	35.6
	KB-12	314	90.3	288	0.0087	33.0	36.8
	LA-4	311	96.1	310	0.0093	33.3	35.7
	LA-5	313	97.9	312	0.0091	34.3	35.5
	MB-13	312	93.0	298	0.0092	32.4	34.7
	MB-18	312	94.8	304	0.0089	34.2	35.6
	NB-17	313	94.3	302	0.0092	32.8	33.8
	QC-30	312	94.3	301	0.0091	33.1	34.7
	RC-24	312	93.0	298	0.0092	32.4	34.0
	SC-23	309	92.1	298	0.0089	33.6	35.1
	JC-23	311	97.4	313	0.0098	31.9	34.1
	KA-5	313	98.8	316	0.0099	31.9	33.8
28,000	KB-14	312	97.0	312	0.0098	31.8	33.9
	MA-4	311	90.7	291	0.0096	30.3	32.5
	NB-14	313	97.4	311	0.0094	33.1	37.4
	PB-12	311	97.0	312	0.0098	31.8	33.5
	PB-13	312	89.8	288	0.0089	32.3	33.9
	QC-31	309	103.6	336	0.0101	33.2	37.5
	RA-5	311	93.4	299	0.0089	33.6	35.7
	SB-18	310	97.0	313	0.0097	32.3	34.1

TABLE C19a
32-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A in. ²	Failure Load P _{ult} , kip	Gross Failure Stress ult, ksi	Apparent Failure Strain ε _f , in./in.	Secant Modulus at Failure E _{sf} , 10 ⁶	Secant Modulus at 20 ksi E _{s20} , 10 ⁶
1,000	JB-13	0.4854	17.1	35.2	0.0090	3.91	4.65
	KC-27	0.4868	16.7	34.2	0.0081	4.22	4.76
	MA-8	0.4860	15.2	31.3	0.0069	4.54	4.88
	MC-28	0.4831	15.8	32.7	0.0083	3.94	5.00
	MA-4	0.4832	15.2	31.5	0.0070	4.50	4.76
	PA-3	0.4831	17.3	35.8	0.0092	3.89	4.65
	QA-6	0.4841	15.0	31.0	0.0069	4.49	4.88
	SA-7	0.4781	14.5	30.3	0.0068	4.46	4.76
	SB-19	0.4826	16.0	33.2	0.0074	4.49	4.88
	JA-5	0.4858	14.3	29.3	0.0066	4.44	4.65
	KC-24	0.4841	16.0	33.1	0.0074	4.47	4.88
	LB-16	0.4872	16.3	33.4	0.0074	4.51	4.88
	MA-6	0.4854	15.5	31.9	0.0071	4.49	4.88
	NA-2	0.4834	15.3	31.5	0.0070	4.50	4.76
	PB-15	0.4833	18.0	37.2	0.0088	4.23	4.76
	PC-25	0.4823	15.8	32.7	0.0076	4.30	4.65
	QC-28	0.4838	15.5	32.0	0.0072	4.44	4.65
	RB-20	0.4721	17.5	37.1	0.0082	4.52	4.88
	RC-27	0.4797	16.0	33.4	0.0073	4.58	5.00
10,000	JC-27 ^a	0.4855	-	-	0.0068	-	-
	JC-28	0.4849	14.3	29.5	0.0068	4.32	4.58
	KC-22	0.4817	14.9	30.8	0.0068	4.56	4.87
	LC-23	0.4821	13.7	28.3	0.0063	4.49	4.65
	MC-25	0.4847	16.6	34.2	0.0080	4.26	4.81
	NB-13	0.4842	17.7	36.6	0.0084	4.36	4.80
	PC-27	0.4831	16.0	33.1	0.0076	4.37	4.65
	QC-23	0.4844	16.5	34.0	0.0076	4.50	4.87
	SA-3	0.4817	15.5	32.1	0.0071	4.55	4.87
	SB-11	0.4730	14.5	30.7	0.0069	4.62	4.90
	JB-11	0.4805	14.1	29.3	0.0063	4.65	5.00
20,000	LC-31	0.4714	15.9	33.7	0.0074	4.55	4.88
	NB-11	0.4750	17.2	36.1	0.0072	5.01	5.26
	NA-6	0.4849	14.9	30.6	0.0067	4.57	4.88
	PB-17	0.4840	16.4	33.9	0.0070	4.64	4.88
	QB-13	0.4862	14.7	30.2	0.0068	4.44	4.88
	QC-22	0.4844	13.8	28.5	0.0063	4.52	4.88
	RA-7	0.4829	13.6	28.2	0.0064	4.41	4.88
	RC-22	0.4841	14.0	28.8	0.0062	4.65	4.88
	SC-27	0.4772	15.5	32.4	0.0070	4.63	5.00
	JB-18	0.4836	14.3	29.5	0.0066	4.47	4.65
	KB-17	0.4828	15.5	32.1	0.0076	4.22	4.65
28,000	LB-19	0.4815	16.7	34.7	0.0075	4.63	4.93
	LC-26	0.4841	16.9	34.9	0.0083	4.20	4.67
	NB-15	0.4828	18.7	38.7	0.0096	4.05	4.83
	NB-18	0.4854	15.0	30.9	0.0068	4.54	4.88
	PA-7	0.4839	16.0	33.1	0.0076	4.36	4.65
	RC-25	0.4826	15.0	31.2	0.0070	4.46	4.76
	RC-31	0.4756	17.0	35.7	0.0078	4.58	4.88
	SB-17	0.4794	13.5	28.2	0.0064	4.40	4.76

a = Failed on loading due to operator error

TABLE C19b
32-PLY DAMAGED HOLE COMPRESSION RESIDUAL STRENGTH RESULTS - TASK II

No. of Fatigue Cycles, N Completed	Specimen ID	Average Gross Area, A mm ²	Failure Load P _{ult.} KN	Gross Failure Stress σ_{ult} MPa	Apparent Failure Strain ϵ_f , mm/mm in 228.6 mm	Secant Modulus at Failure E _f , GPa	Secant Modulus at 138 MPa E _{s138} GPa
1,000	JB-13	313	76.0	243	0.0090	27.0	32.1
	KC-27	314	74.3	236	0.0081	29.1	32.8
	MA-8	314	67.6	216	0.0069	31.3	33.6
	NC-28	312	70.3	225	0.0083	27.2	34.5
	NA-4	312	67.6	217	0.0070	31.0	32.8
	PA-3	312	77.0	247	0.0092	26.8	32.1
	QA-6	312	66.7	214	0.0069	31.0	33.6
	SA-7	308	64.5	209	0.0068	30.8	32.8
	SB-19	311	71.2	229	0.0074	31.0	33.6
	JA-5	313	63.6	202	0.0066	30.6	32.1
	KC-24	312	71.2	228	0.0074	30.8	33.6
	LB-16	314	72.5	230	0.0074	31.1	33.6
	MA-6	313	69.0	220	0.0071	31.0	33.6
	NA-2	312	68.1	217	0.0070	31.0	32.8
	PB-15	312	80.1	256	0.0088	29.2	32.8
	PC-25	311	70.3	225	0.0076	29.6	32.1
	QC-28	312	69.0	221	0.0072	30.6	32.1
	RB-20	305	77.8	256	0.0082	31.2	33.6
	RC-27	310	71.2	230	0.0073	31.6	34.5
10,000	JC-27 ^a	313	-	-	-	-	-
	JC-28	313	63.6	203	0.0068	29.8	31.6
	KC-22	311	66.3	212	0.0068	31.4	33.6
	LC-23	311	60.9	195	0.0063	32.1	32.1
	MC-25	313	73.8	236	0.0080	29.4	33.1
	NB-13	312	78.7	252	0.0084	30.1	33.1
	PC-27	312	71.2	228	0.0076	30.1	32.1
	QC-23	312	73.4	234	0.0076	31.0	33.6
	SA-3	311	69.0	221	0.0071	31.4	33.6
	SB-11	305	64.5	212	0.0069	30.5	33.8
	JB-11	310	62.7	202	0.0063	32.1	34.5
	LC-31	304	70.7	232	0.0074	31.4	33.6
	NB-11	306	76.5	249	0.0072	34.5	36.3
	NA-6	313	66.3	211	0.0067	31.5	33.6
	PB-17	312	73.0	234	0.0070	32.0	33.6
	QB-13	314	65.4	208	0.0068	30.6	33.6
	QC-22	312	61.4	196	0.0063	31.2	33.6
	RA-7	312	60.5	194	0.0064	30.4	33.6
	RC-22	312	62.3	199	0.0062	32.1	33.6
	SC-27	308	68.9	223	0.0070	31.9	34.5
20,000	JB-18	312	63.6	203	0.0066	30.8	32.1
	KB-17	311	69.0	221	0.0076	29.1	32.1
	LB-19	311	74.3	239	0.0075	31.9	34.0
	LC-26	312	75.2	241	0.0083	29.0	32.2
	NB-15	312	83.2	267	0.0096	27.9	33.3
	NB-18	313	66.7	213	0.0068	31.3	33.6
	PA-7	312	71.2	228	0.0076	30.1	32.1
	RC-25	311	66.7	215	0.0070	30.8	32.8
	RC-31	307	75.6	246	0.0078	31.6	33.6
	SB-17	309	60.0	194	0.0064	30.3	32.8

^a = Failed on loading due to operator error.

APPENDIX D

Damage Growth Characteristics
Under Fatigue Loading

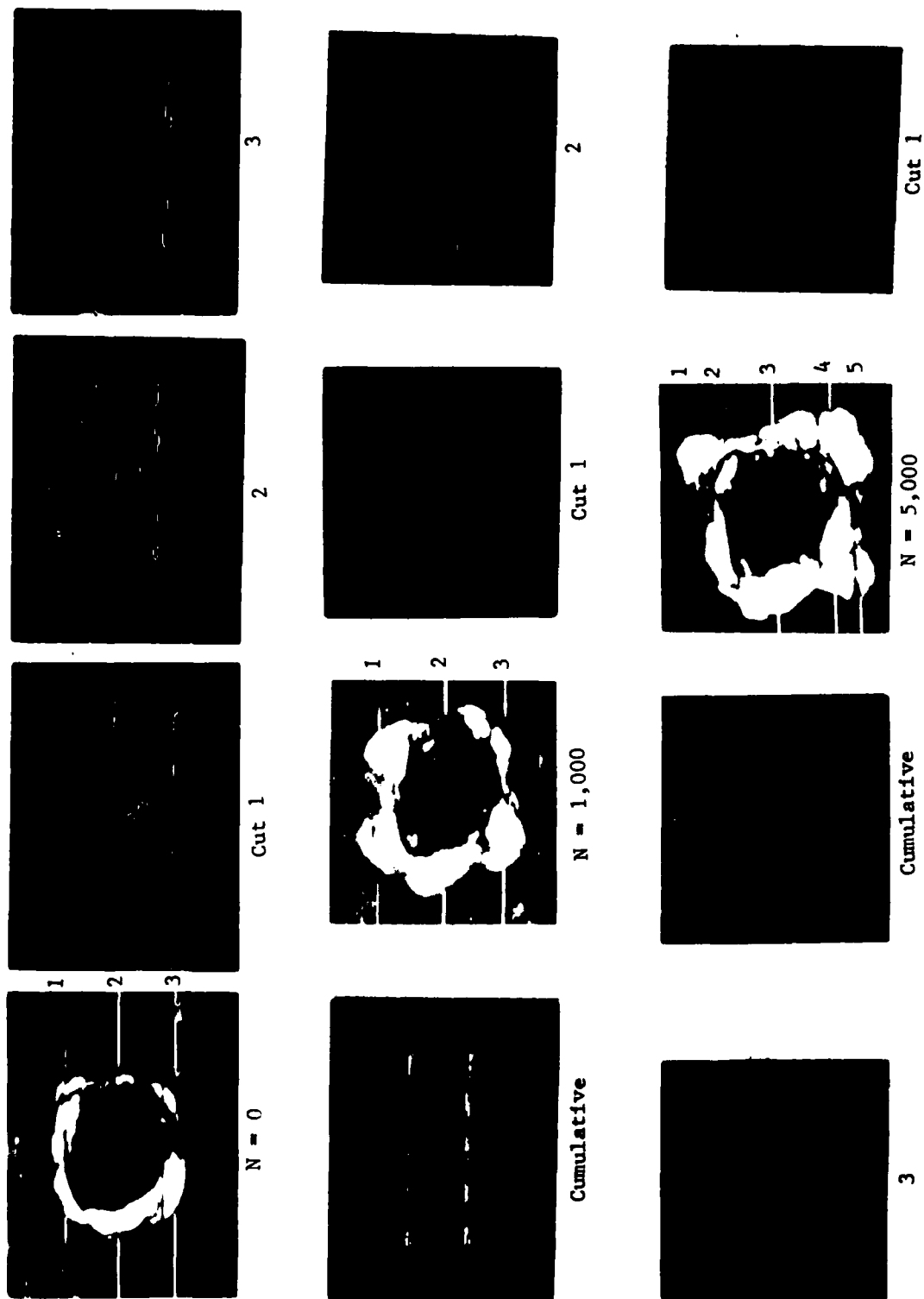


Figure D1a: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber Short Lived Specimens (FA-3 $N_f = 47,846$)

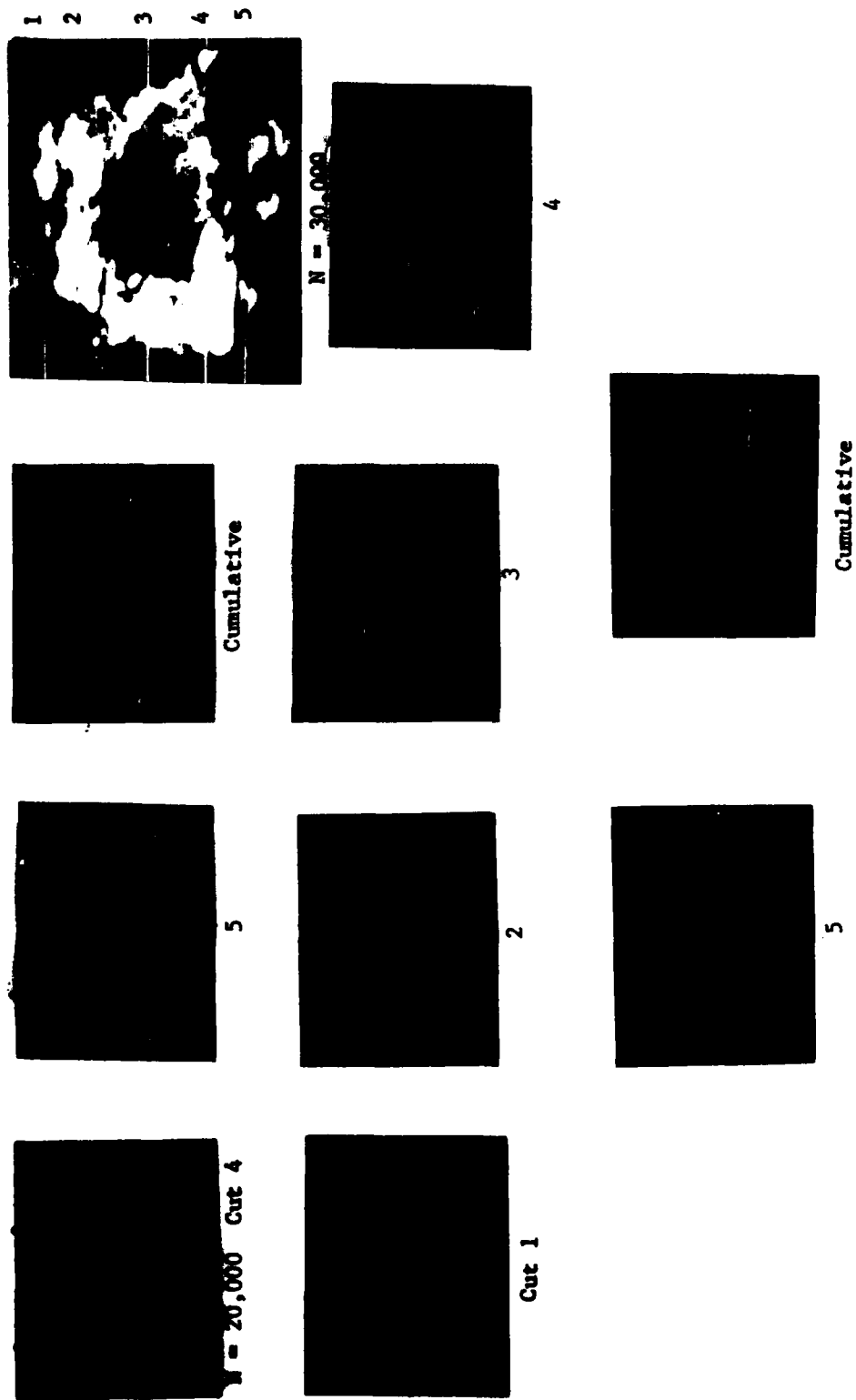


Figure D1c: Damage Growth Characteristics of 24-ply, 67% 0° Fiber Short Lived Specimens (FA-3 $N_f = 47,846$)

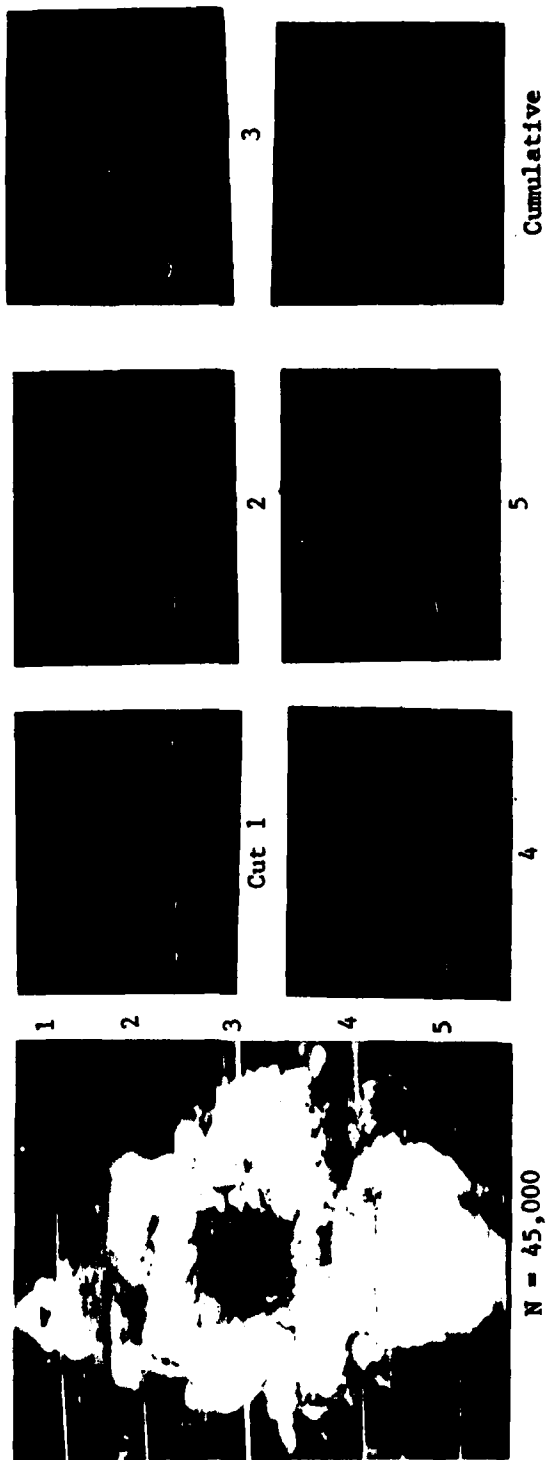


Figure D1d: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber
Short Lived Specimens (FA-3 $N_f = 47,846$)

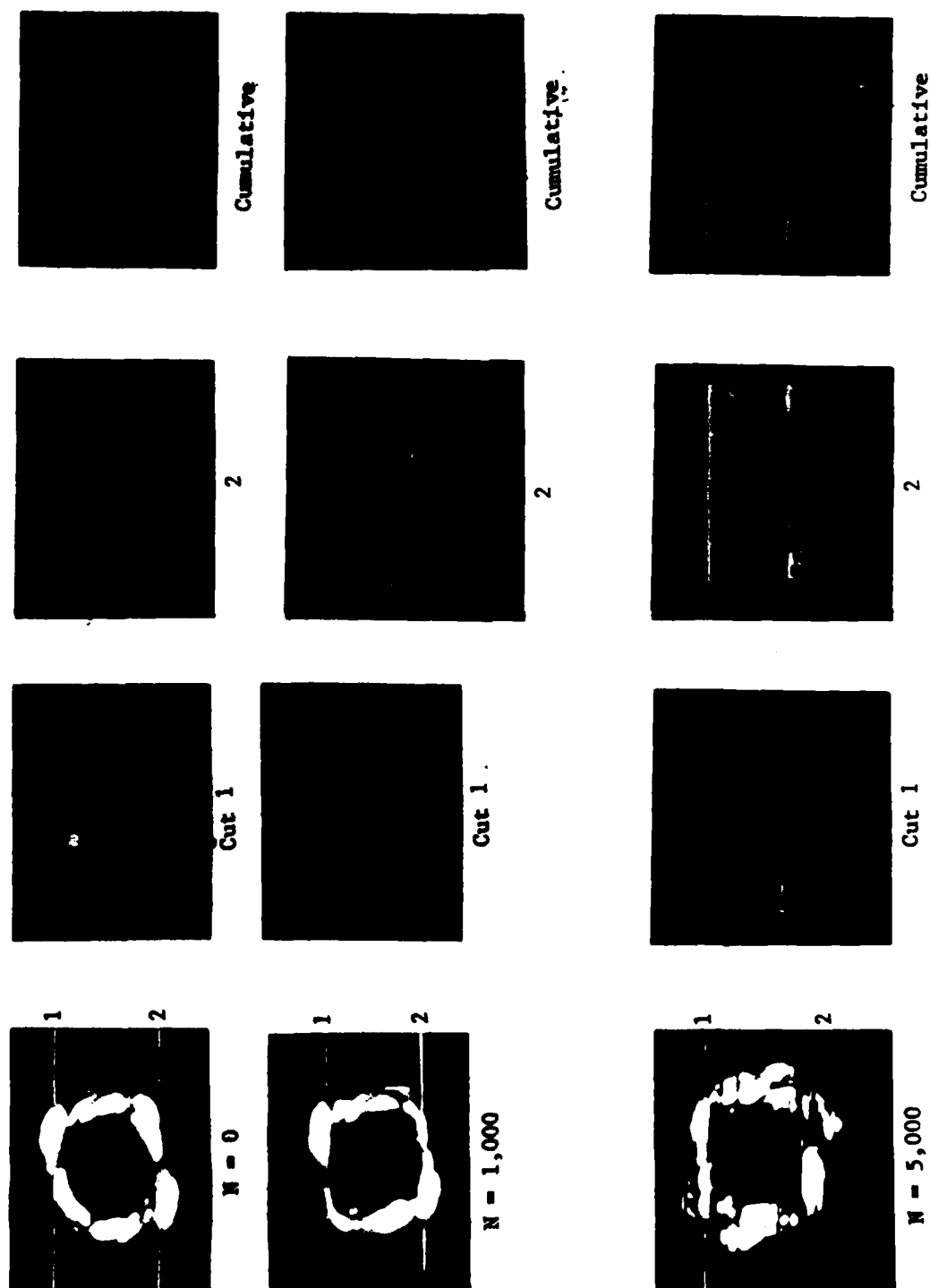


Figure D2a: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber
Long Lived Specimens (HC-26 $N_f = 448,633$)

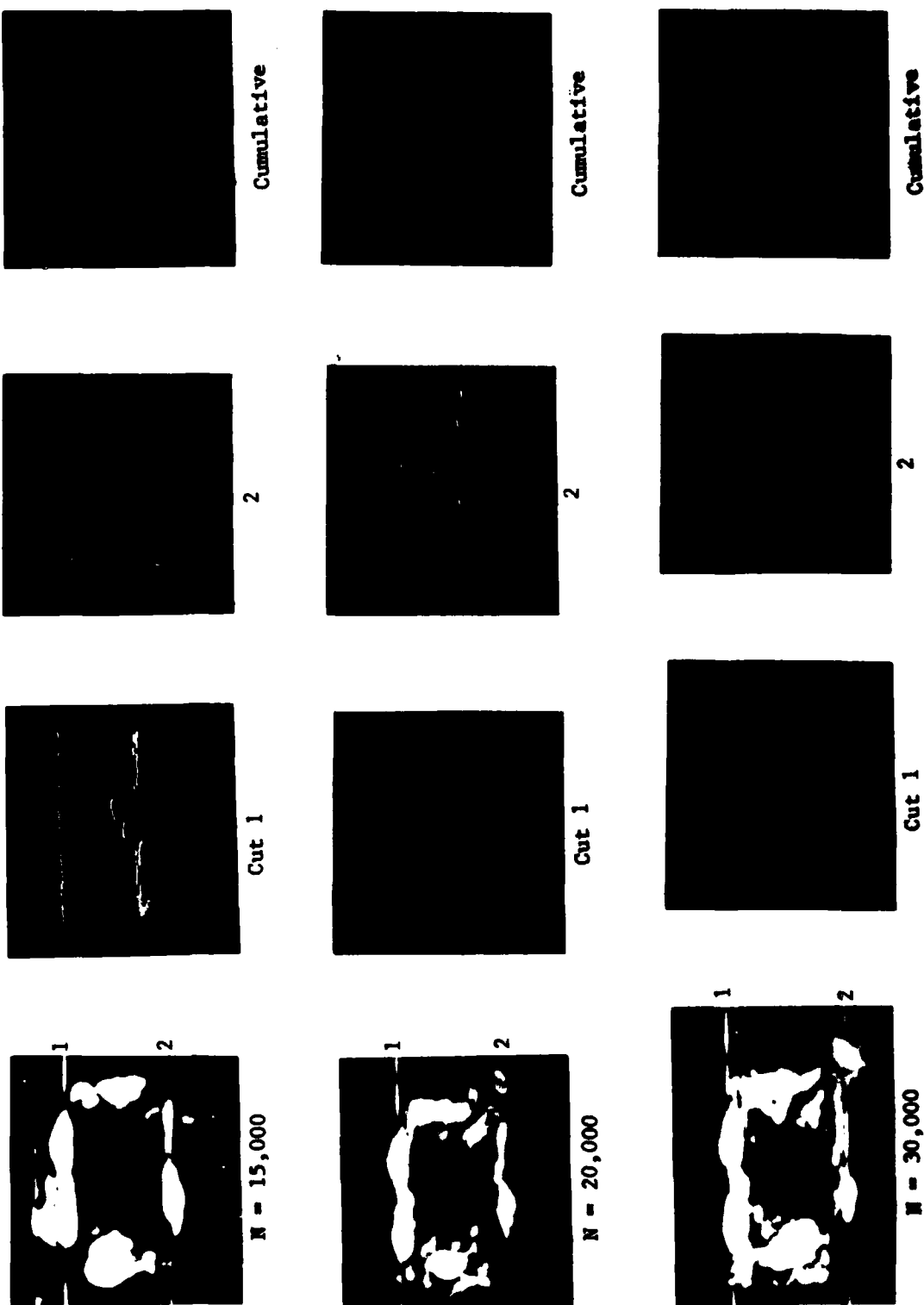


Figure D2b: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber Long Lived Specimens (HC-26 $N_f = 448,633$)

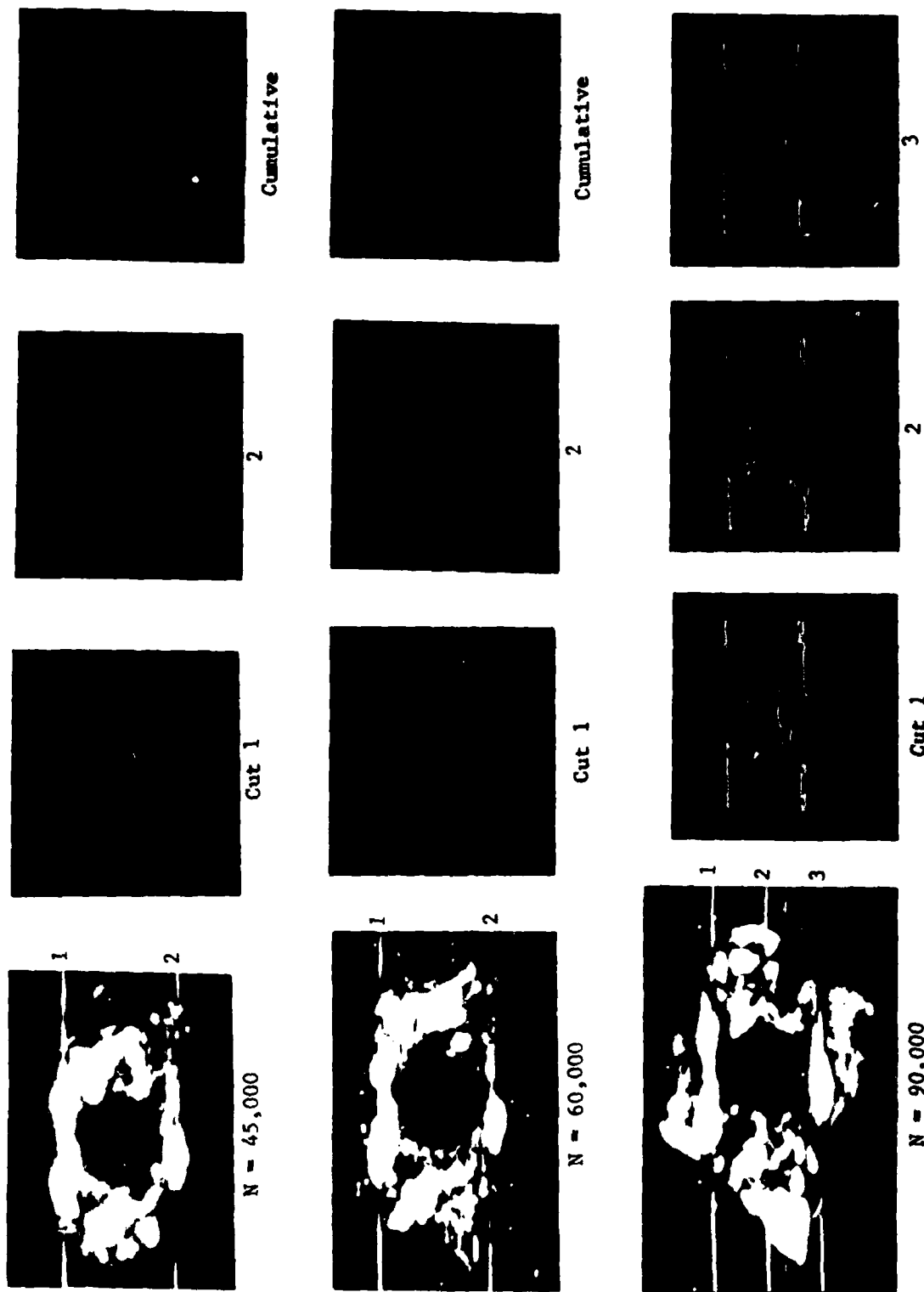


Figure D2c: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber Long Lived Specimens (HC-26 $N_f = 448,633$)

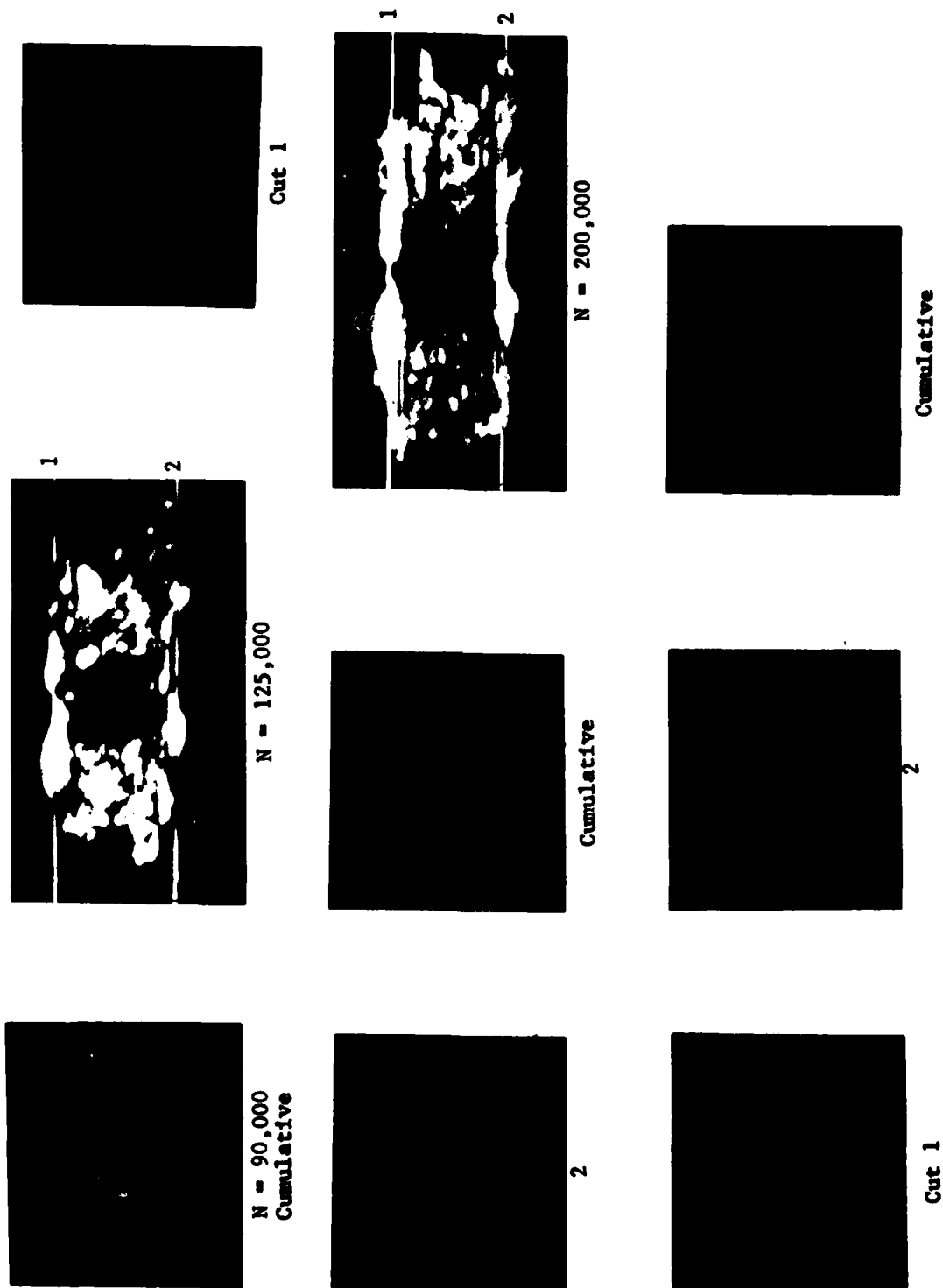


Figure D2d: Damage Growth Characteristics of 24-Ply , 67% 0° Fiber
Long Lived Specimens (HC-26 $N_f = 448,633$)

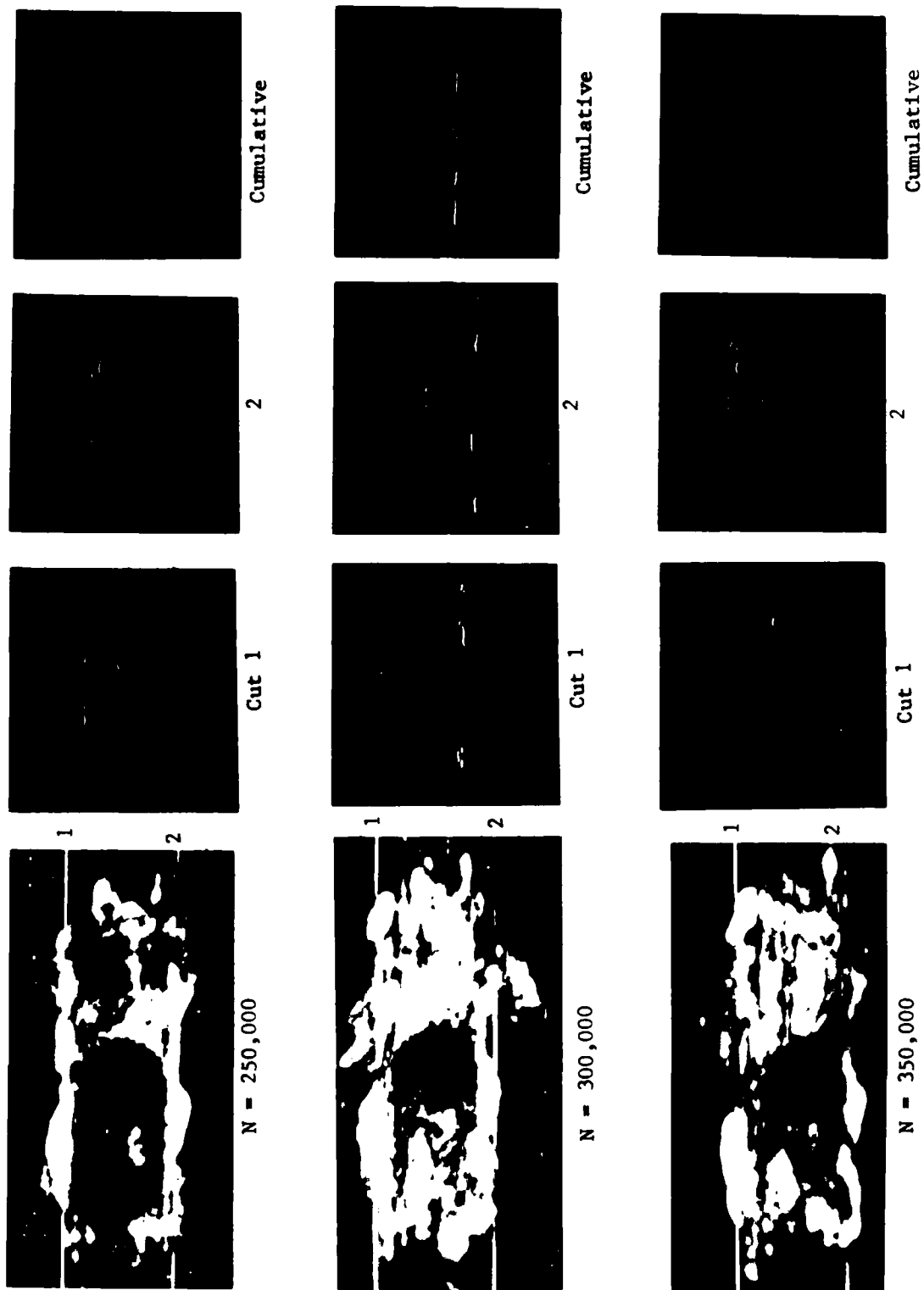


Figure D2e: Damage Growth Characteristics of 24-Ply, 67% 0° Fiber
Long Lived Specimens (HC-26 $N_f = 448,633$)

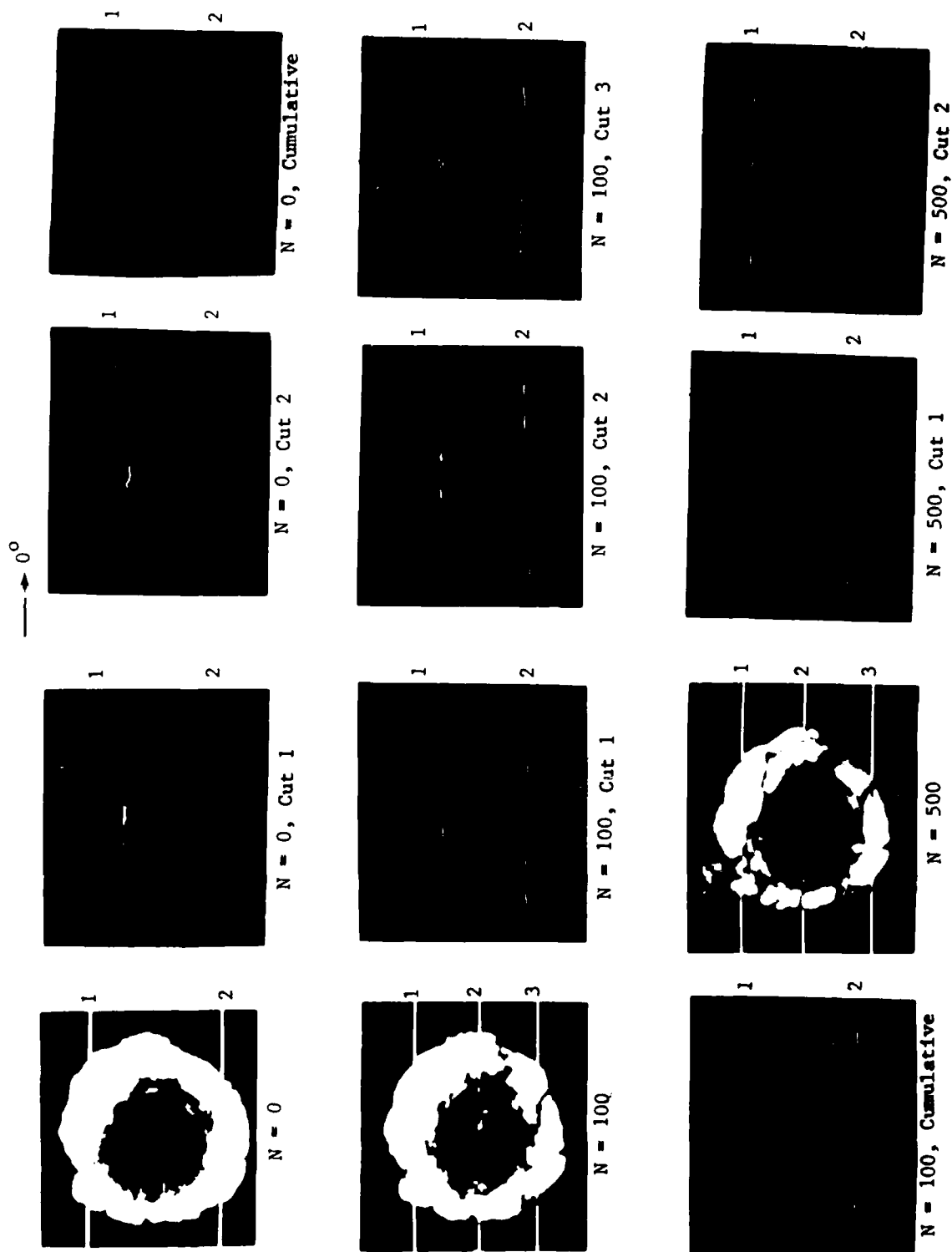


Figure D3a: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, $N_f = 27,673$)

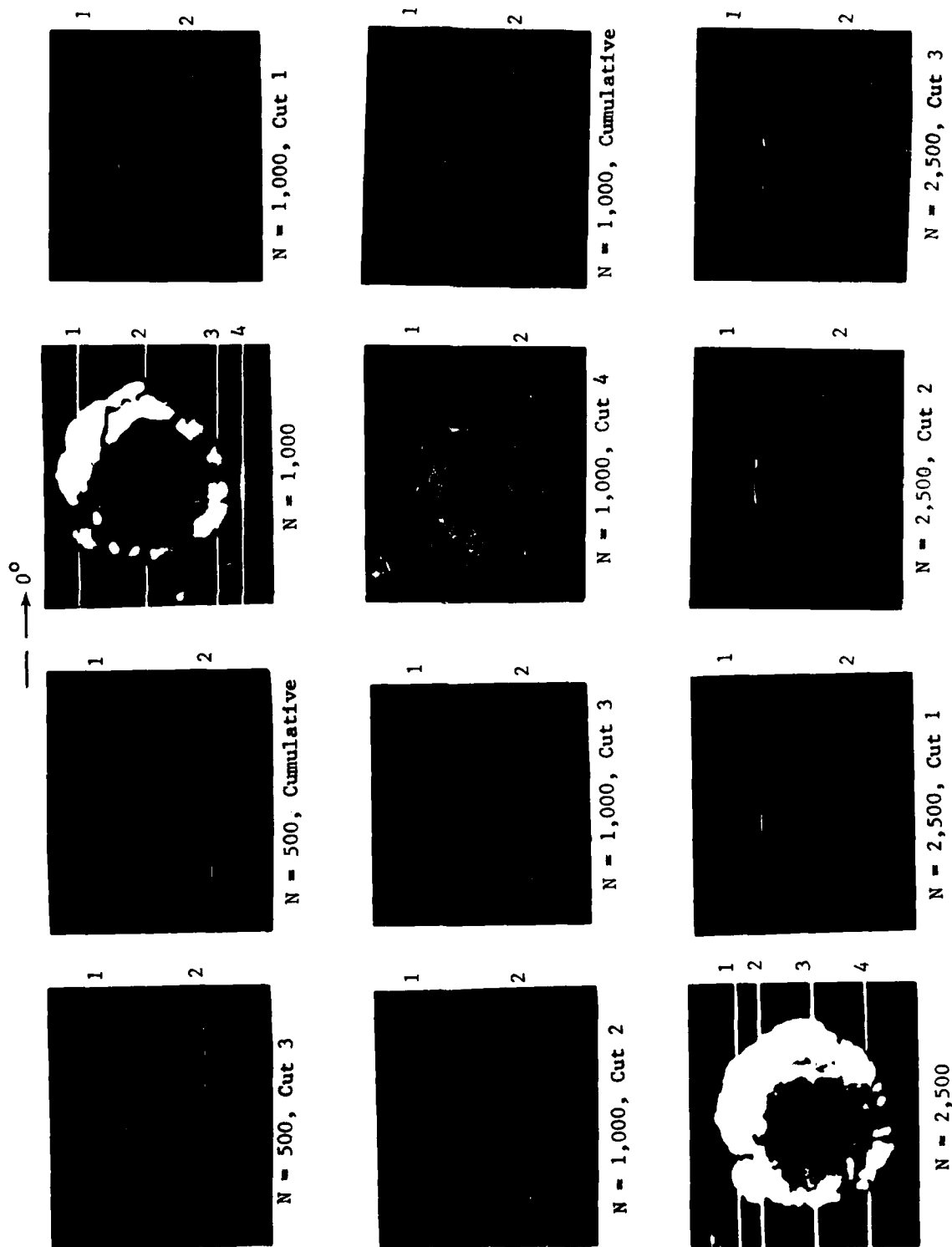


Figure D3b: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, $N_f = 27,673$)

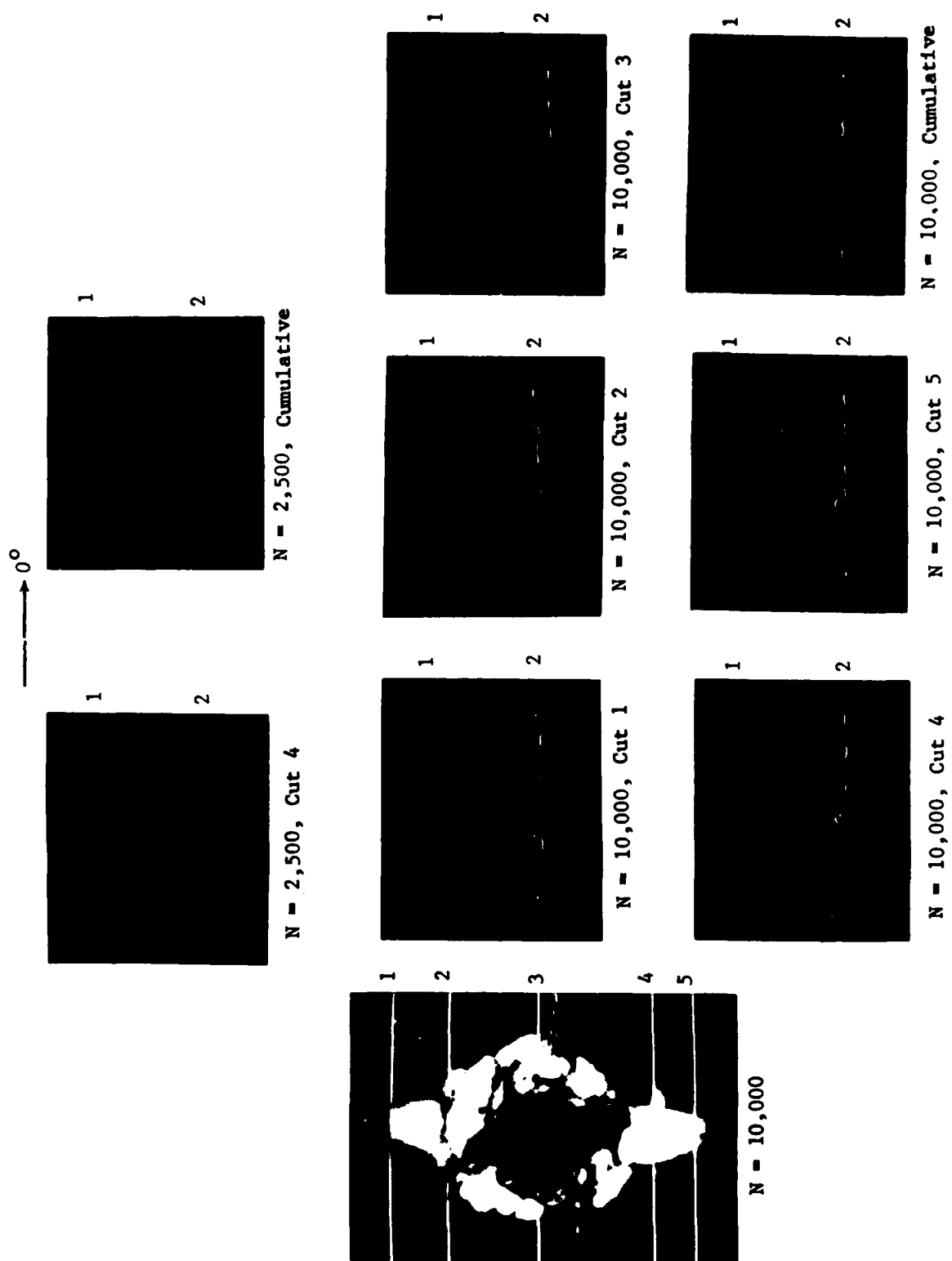


Figure D3c: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, $N_f = 27,673$)

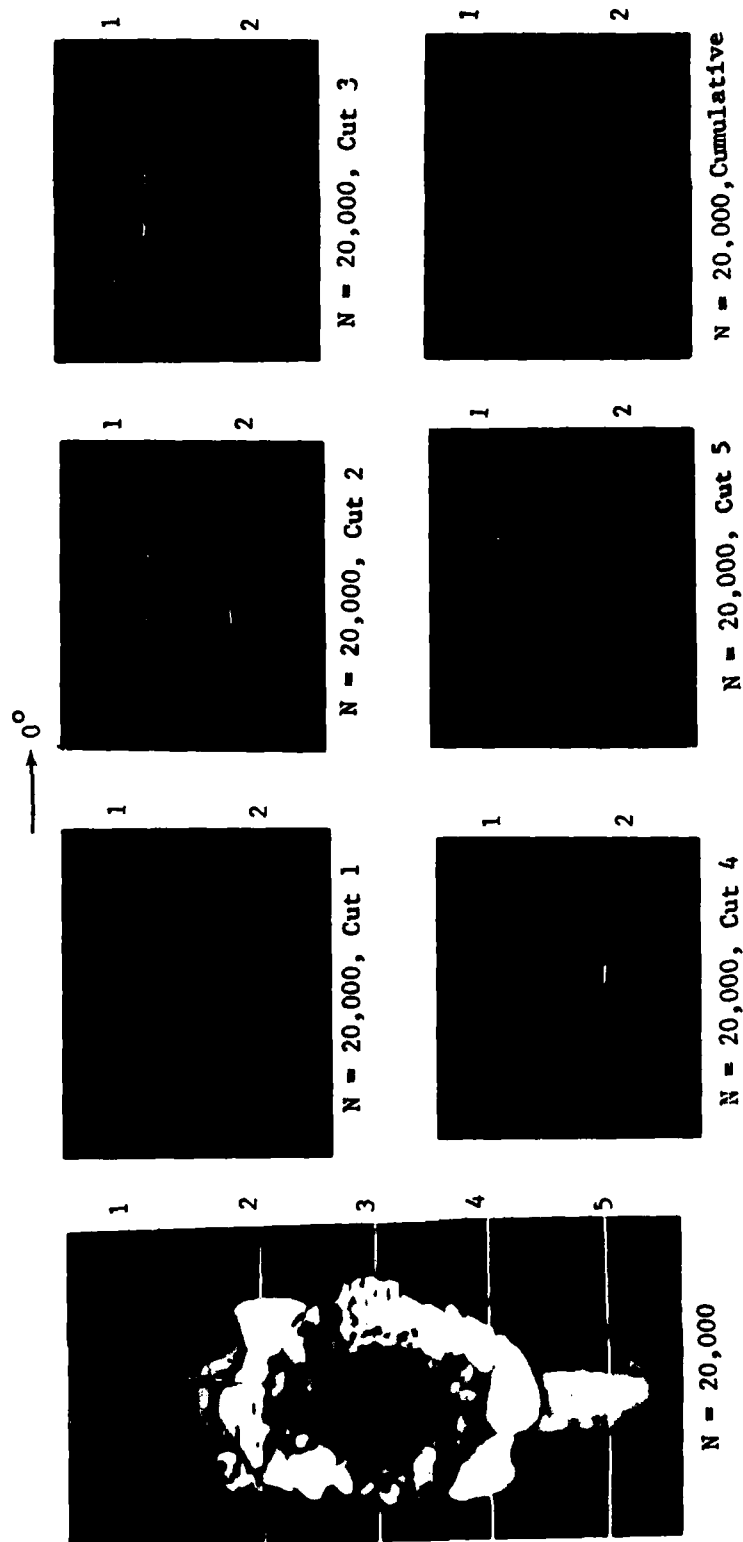


Figure 3Dd: Damage Growth Characteristics of 32-Ply Quasi-Isotropic Short Lived Specimens (MB-17, $N_f = 27,673$)

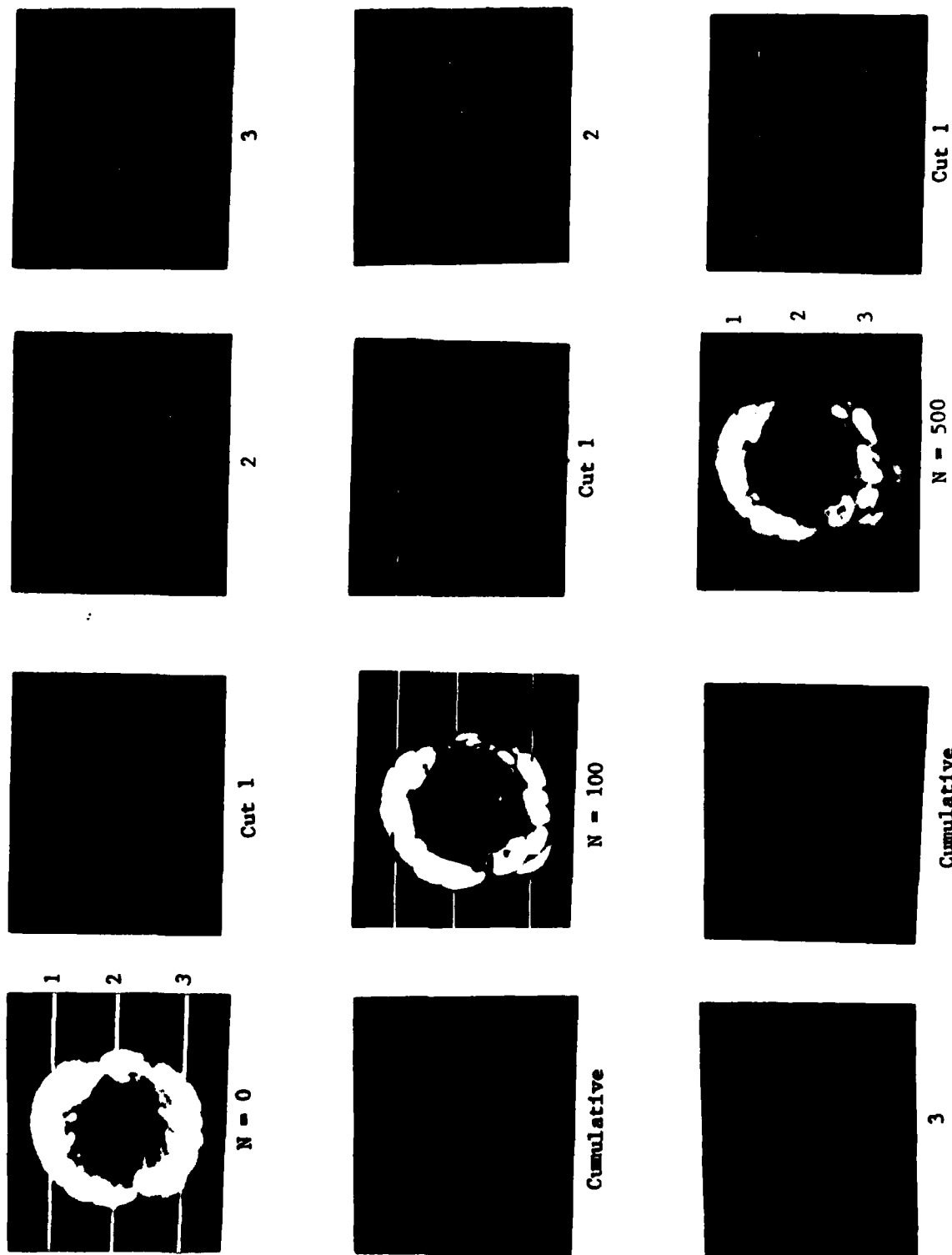


Figure D4a: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 $N_f = 188,907$)

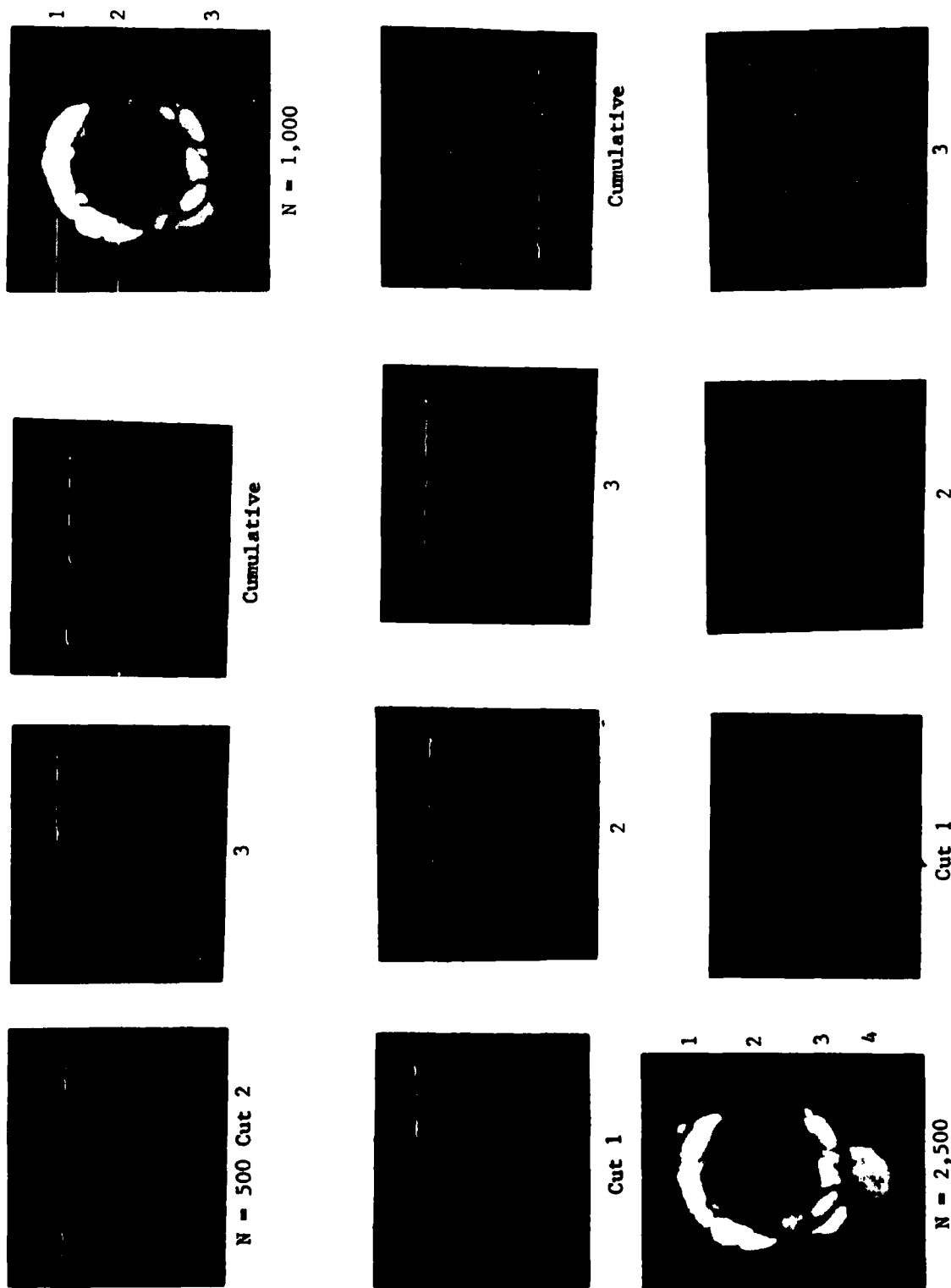


Figure D4b: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 $N_f = 188,907$)

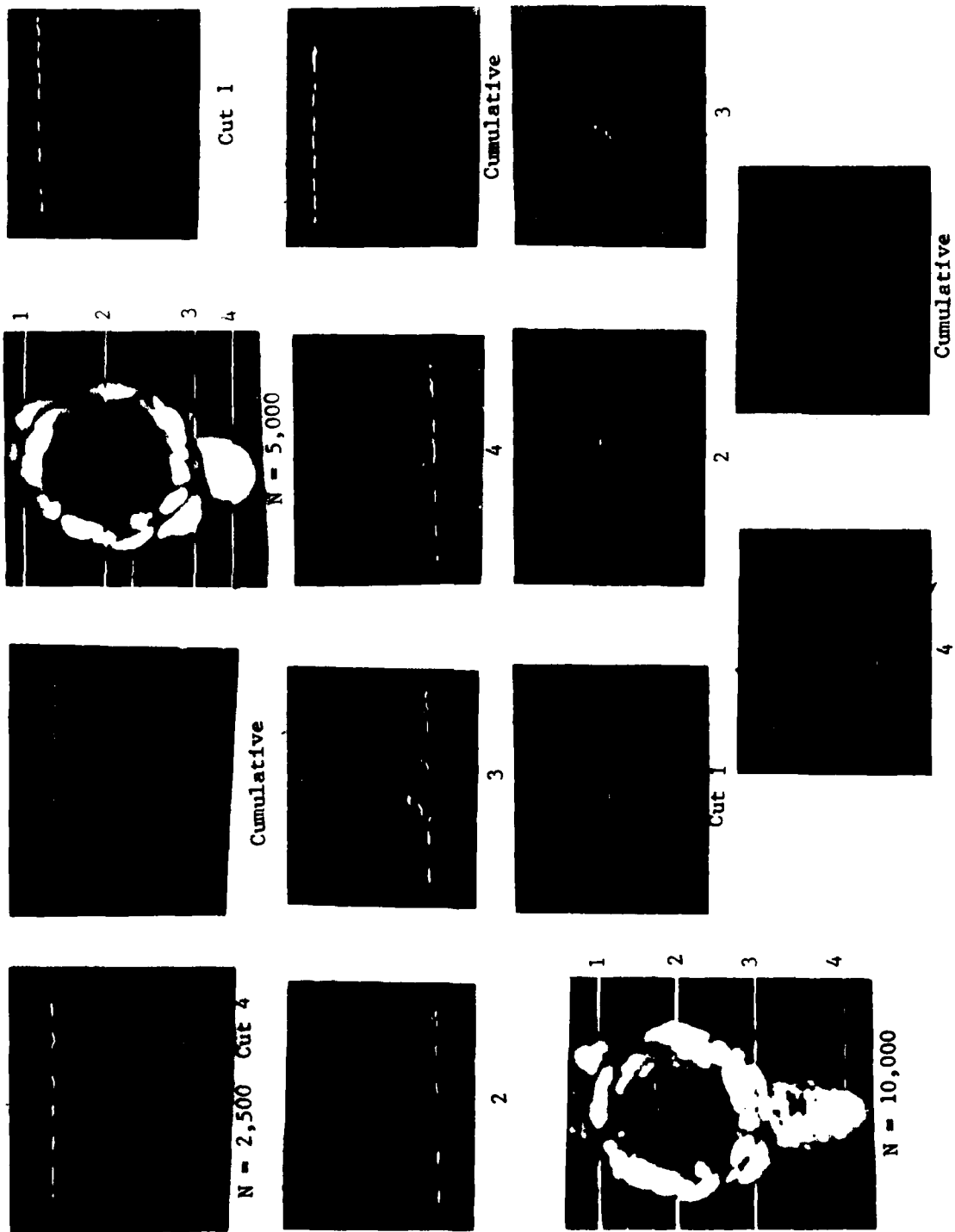
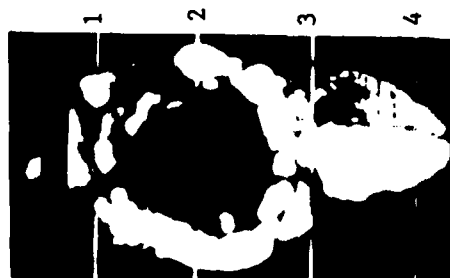


Figure D4c: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 $N_f = 188,907$)



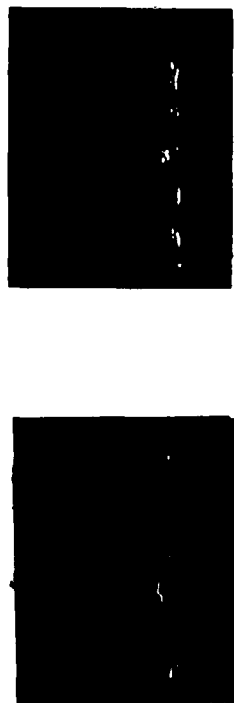
N = 20,000



N = 50,000



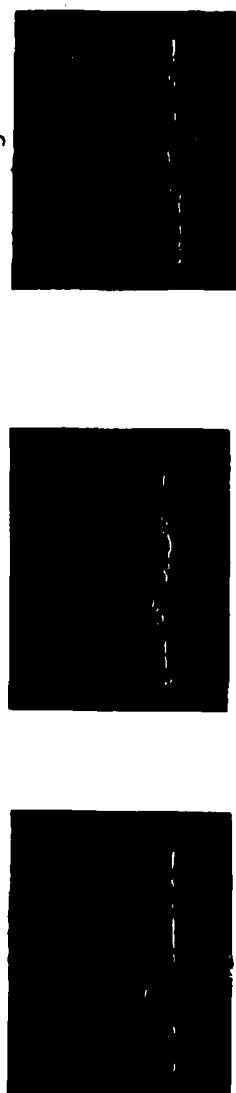
Cut 1



Cumulative



Cut 1



5

Cumulative

Figure D4d: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 $N_f = 188,907$)

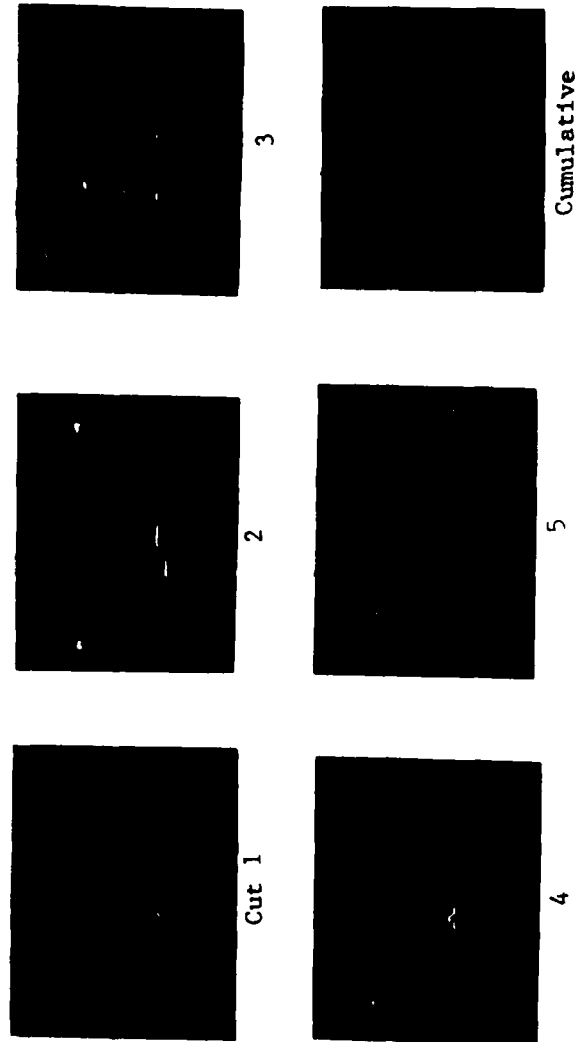


Figure D4e: Damage Growth Characteristics of 32-Ply, Quasi-Isotropic Long Lived Specimens (LC-30 $N_f = 188,907$)

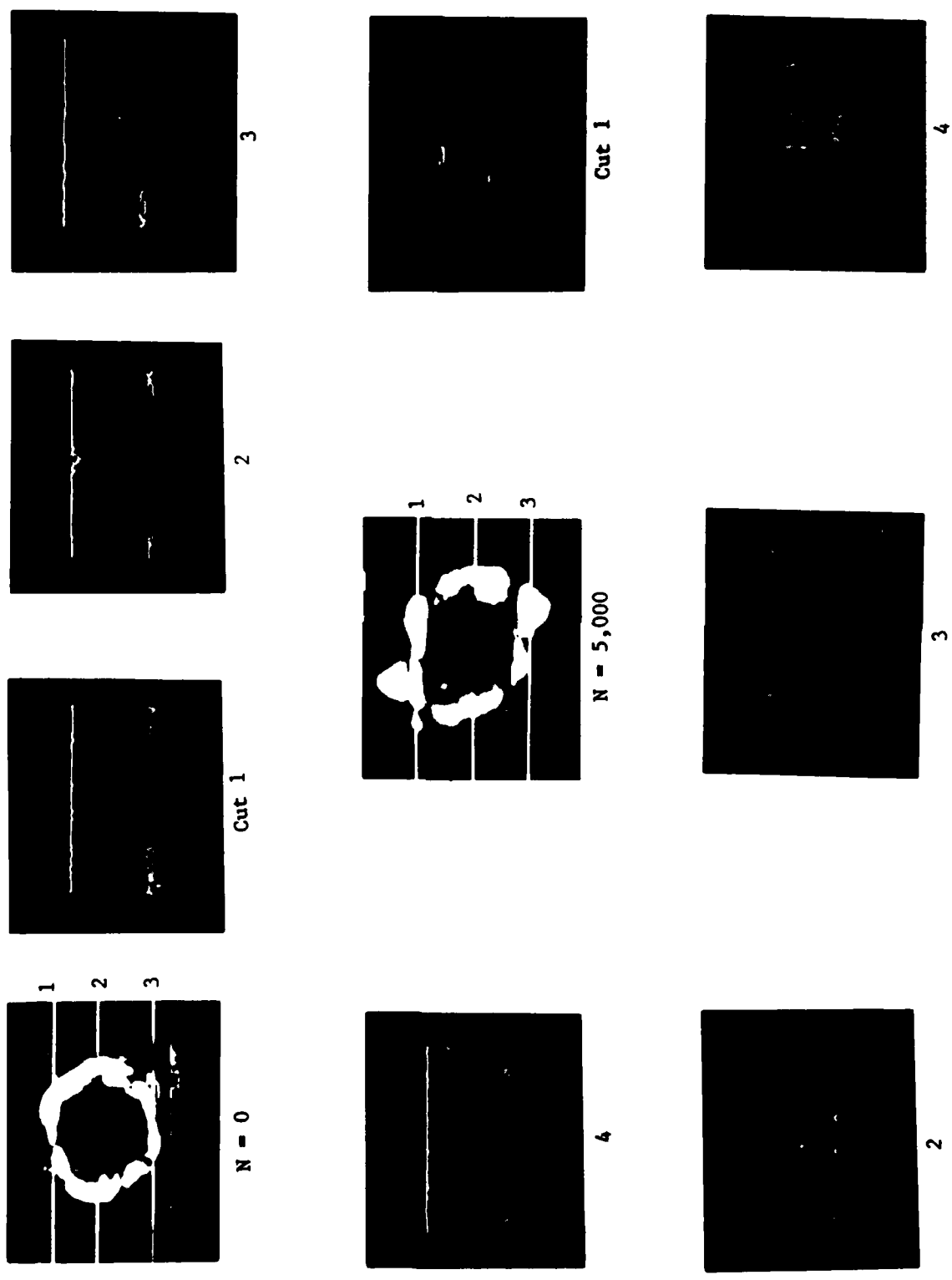


Figure D5a: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, $N_f = 569,499$)

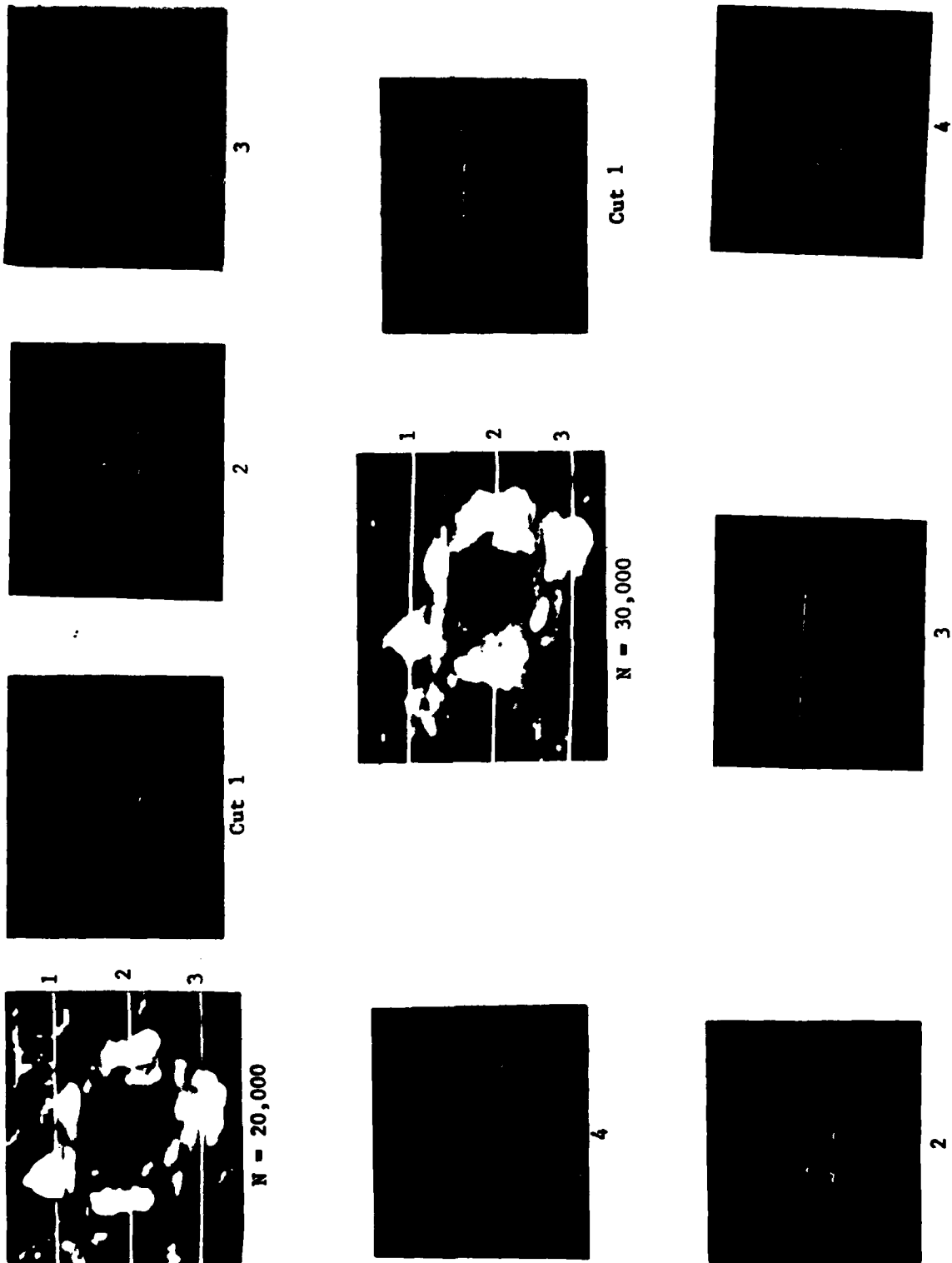


Figure D5b: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, $N_f = 569,499$)

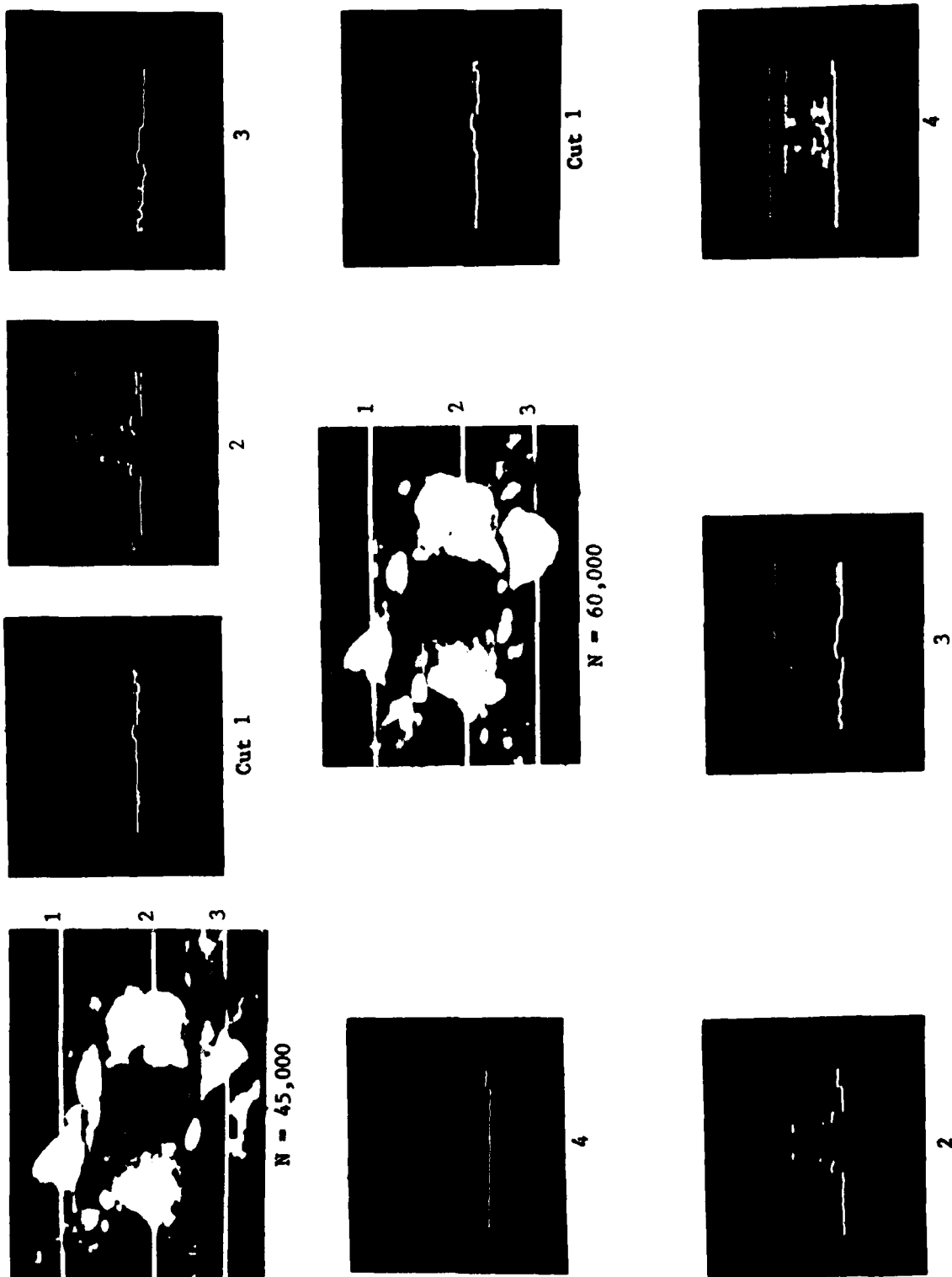


Figure D5c: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, $N_f = 569,499$)

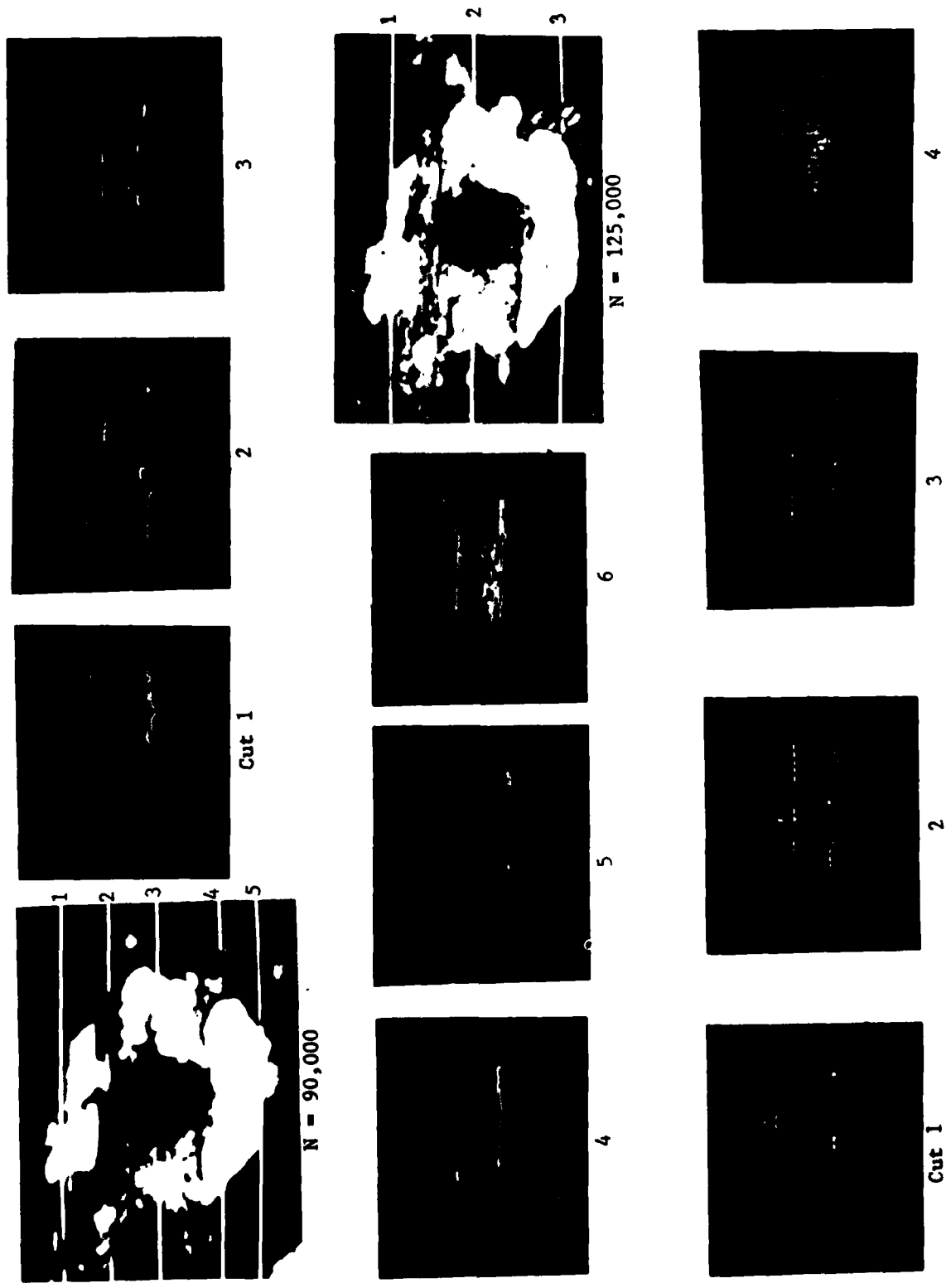
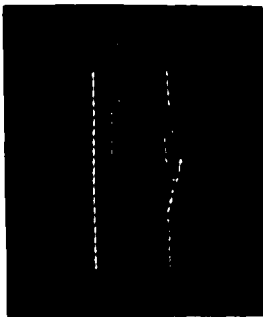
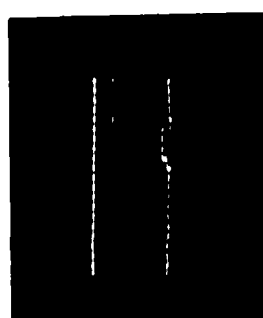


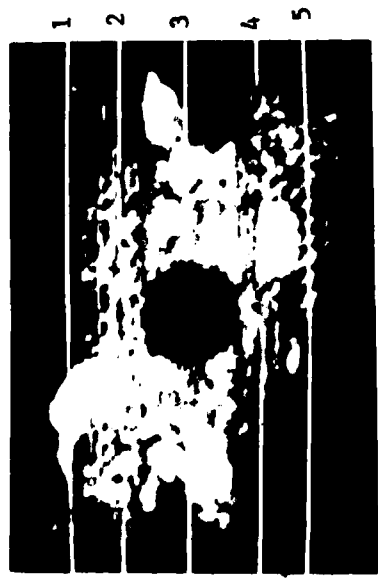
Figure D5d: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, $N_f = 569,499$)



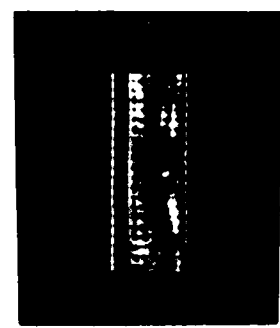
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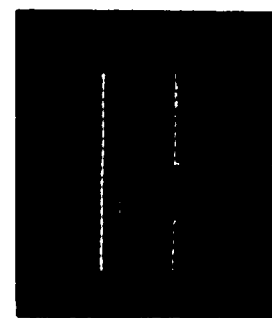
Cut 1



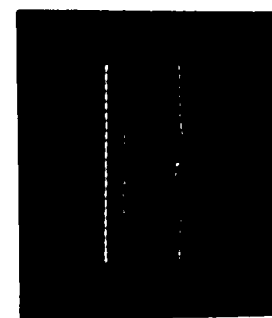
N = 225,000



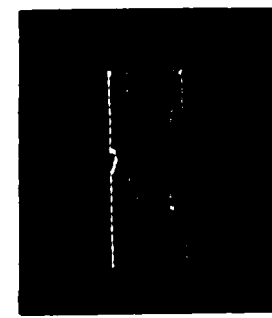
Cumulative



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4



3

Figure D5e: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support ($CA-6$, $N_f = 569,499$)

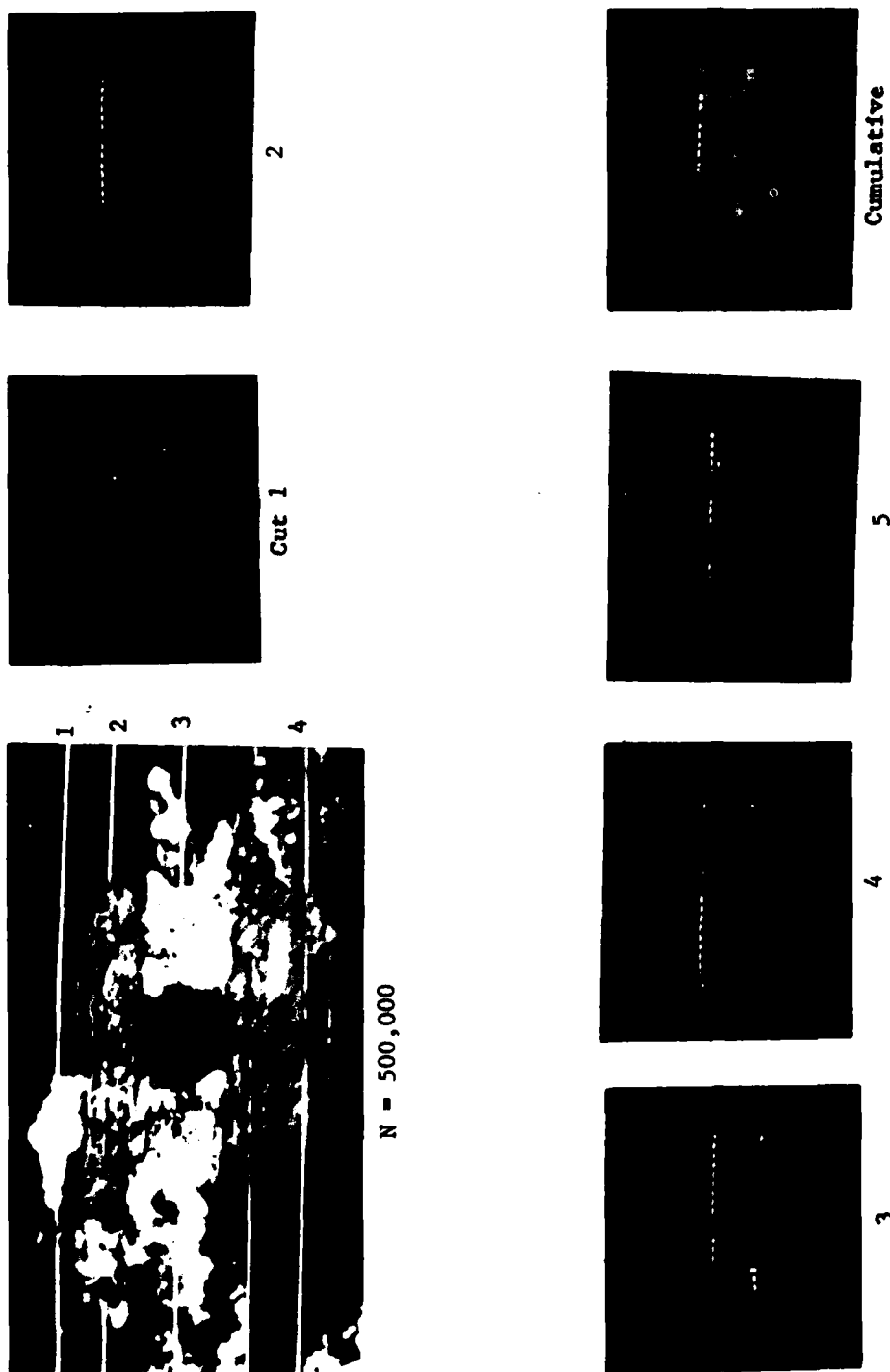


Figure D5f: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition A, 4-Bar Support (CA-6, $N_f = 569,499$)

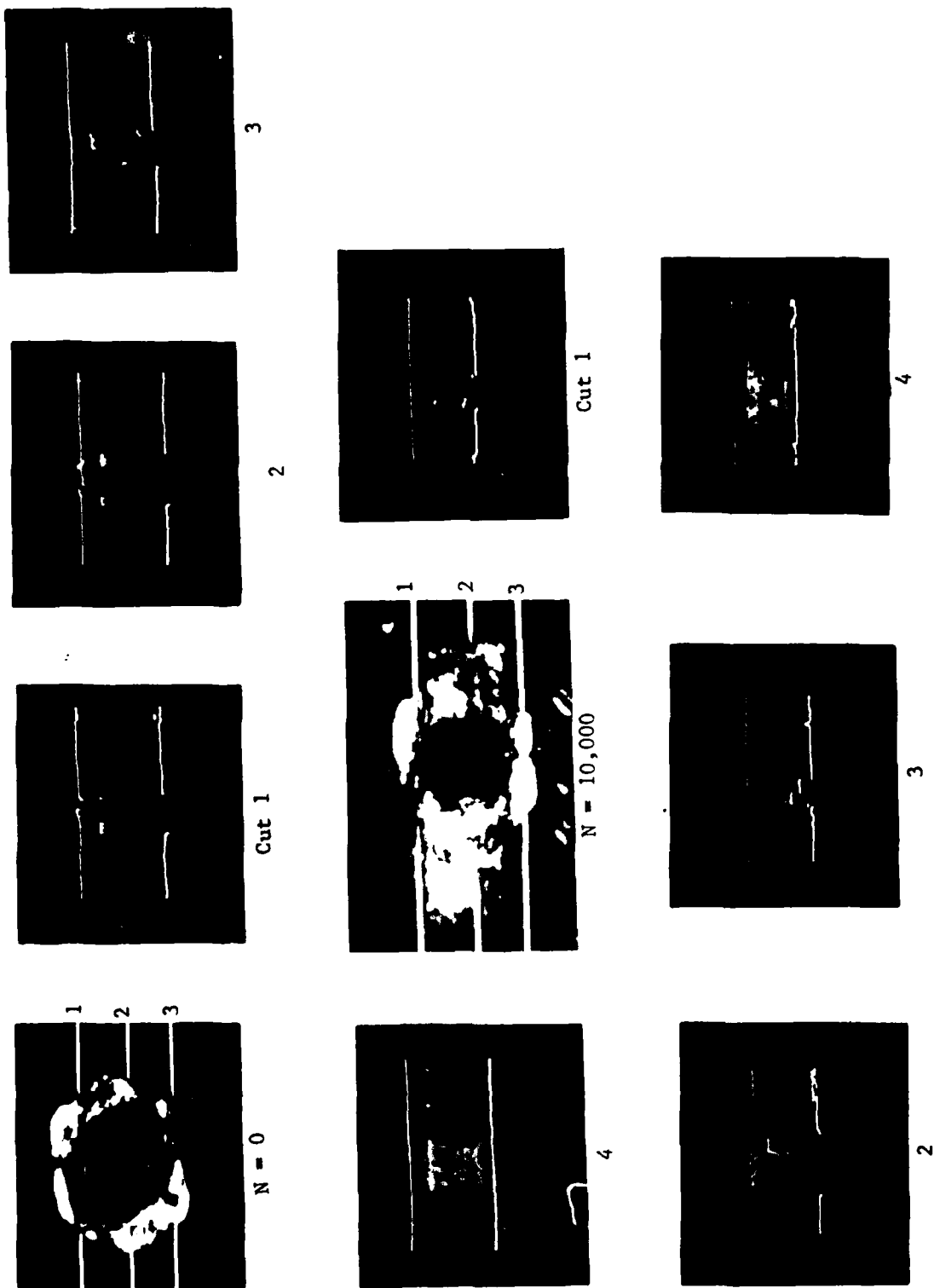


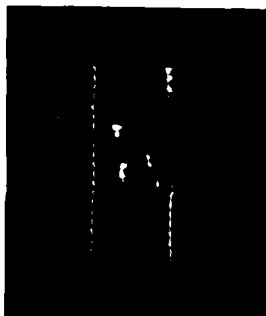
Figure D6a: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, $R = -0.3$ (AB-11, 12×10^6 without failure)



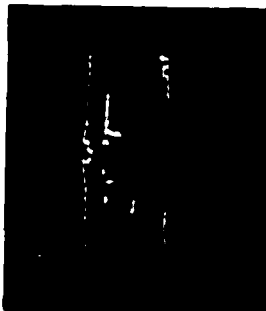
Figure D6b: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, $R = -0.3$ (AB-11, 12×10^6 without failure)



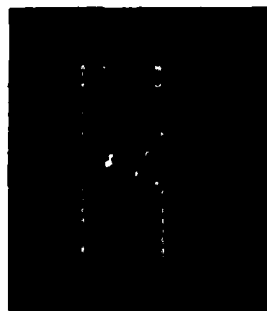
N = 90,000



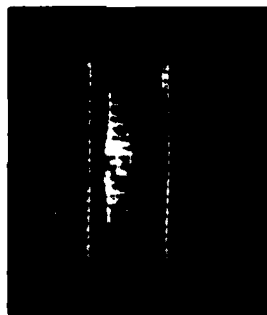
Cut 1



2



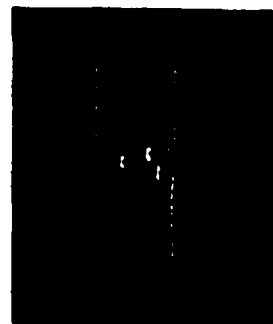
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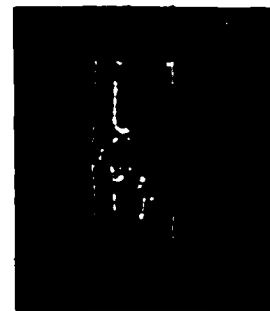
4



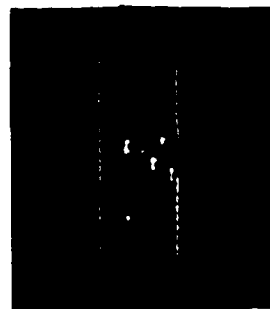
N = 125,000



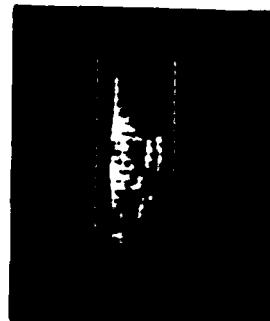
Cut 1



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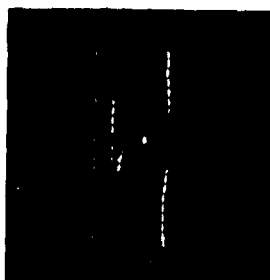


4

Figure D6c: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, $R = -0.3$ (AB-11, 12×10^6 without failure)



N = 500,000



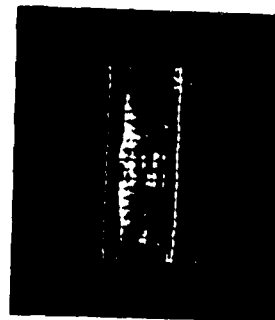
Cut 1



2



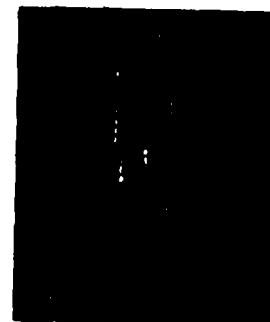
3



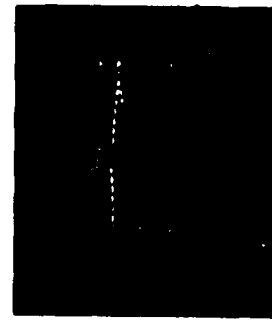
4



N = 1 X 10⁶



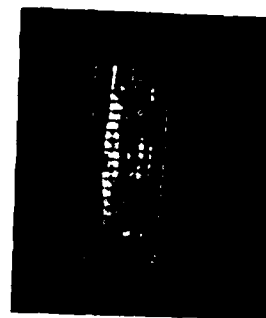
Cut 1



2



3

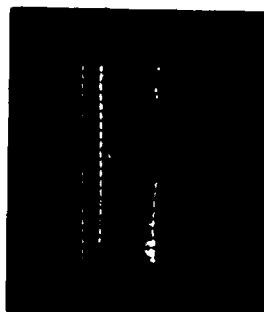


4

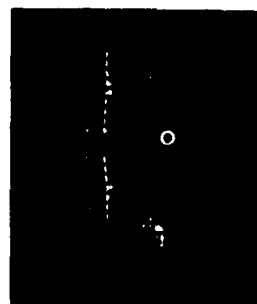
Figure D6d: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, R = -0.3 (AB-11, 12 x 10⁶ without failure)



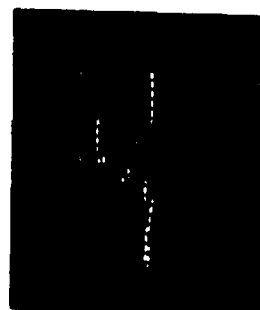
$N = 2 \times 10^6$



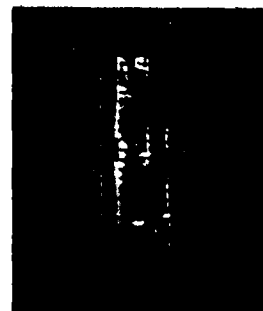
Cut 1



2



3



4

Figure D6e: Damage Growth Characteristics of the 24-Ply Laminate for Fatigue Condition B, $R = -0.3$ (AB-11, 12×10^6 without failure)

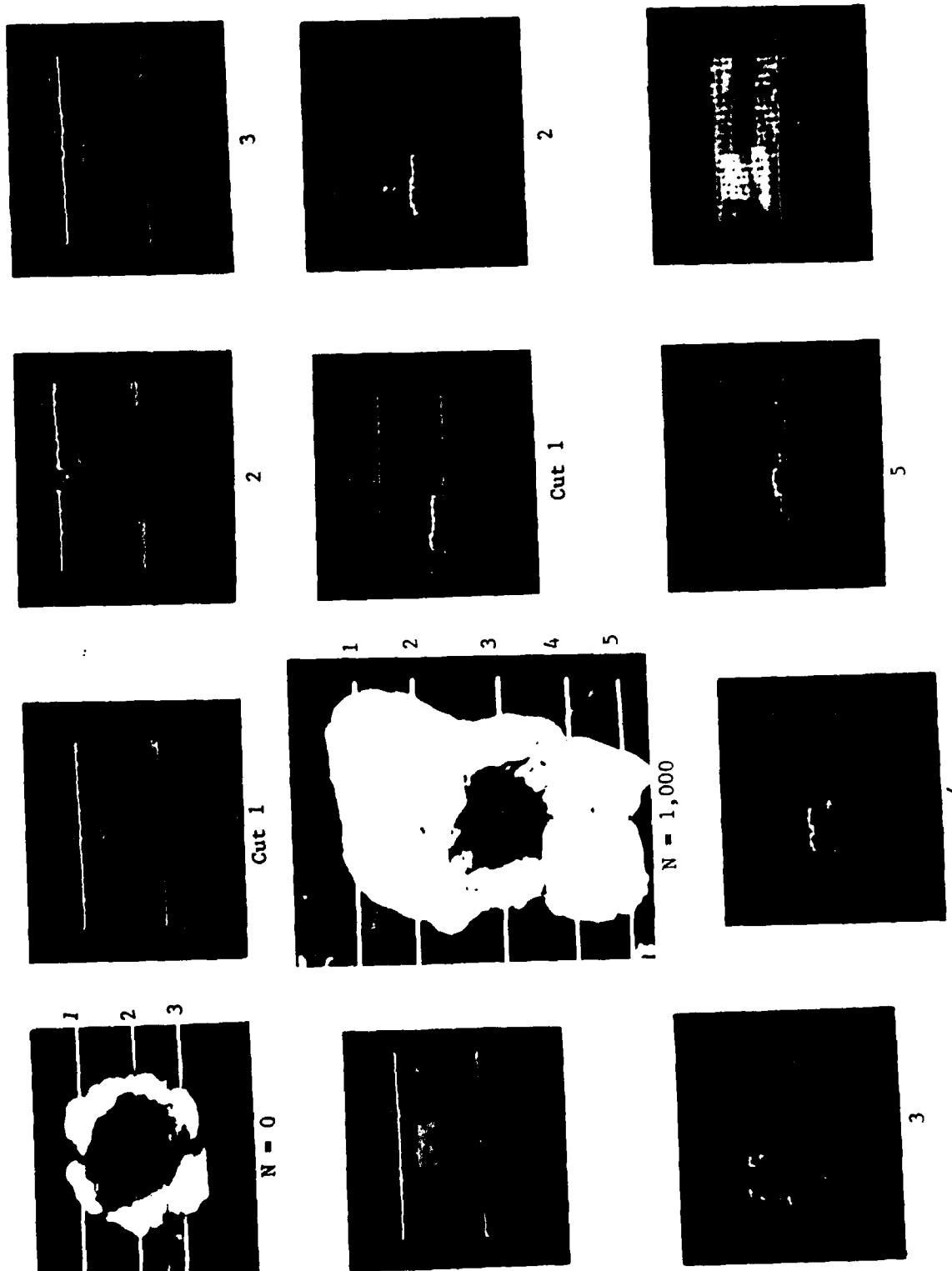


Figure D7: Damage Growth Characteristics of the 32-Ply Laminate for
 Fatigue Condition C, 180°F (82°C) BBC-12, $N_f = 2,460$

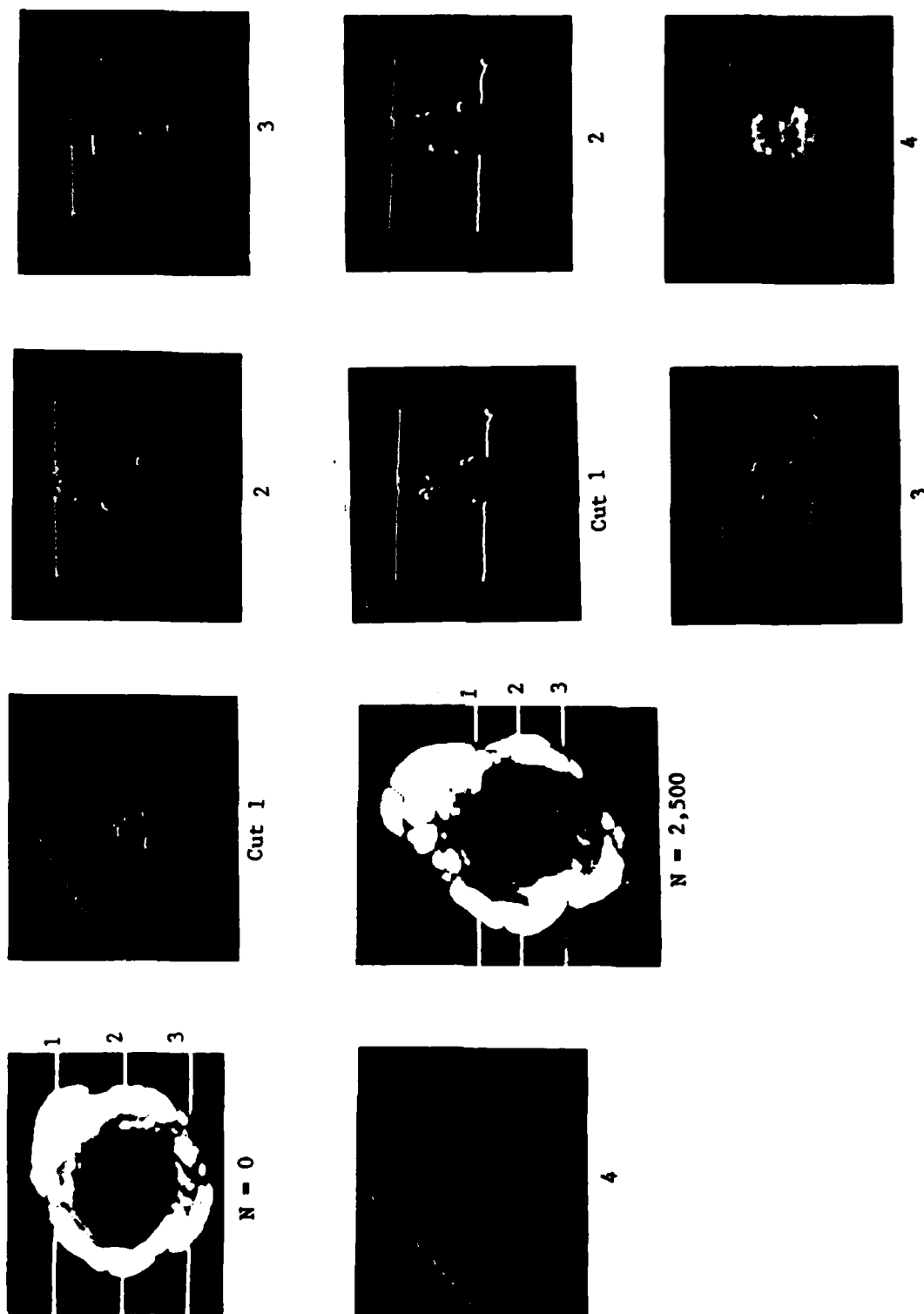


Figure D8a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, $N_f = 58,005$)

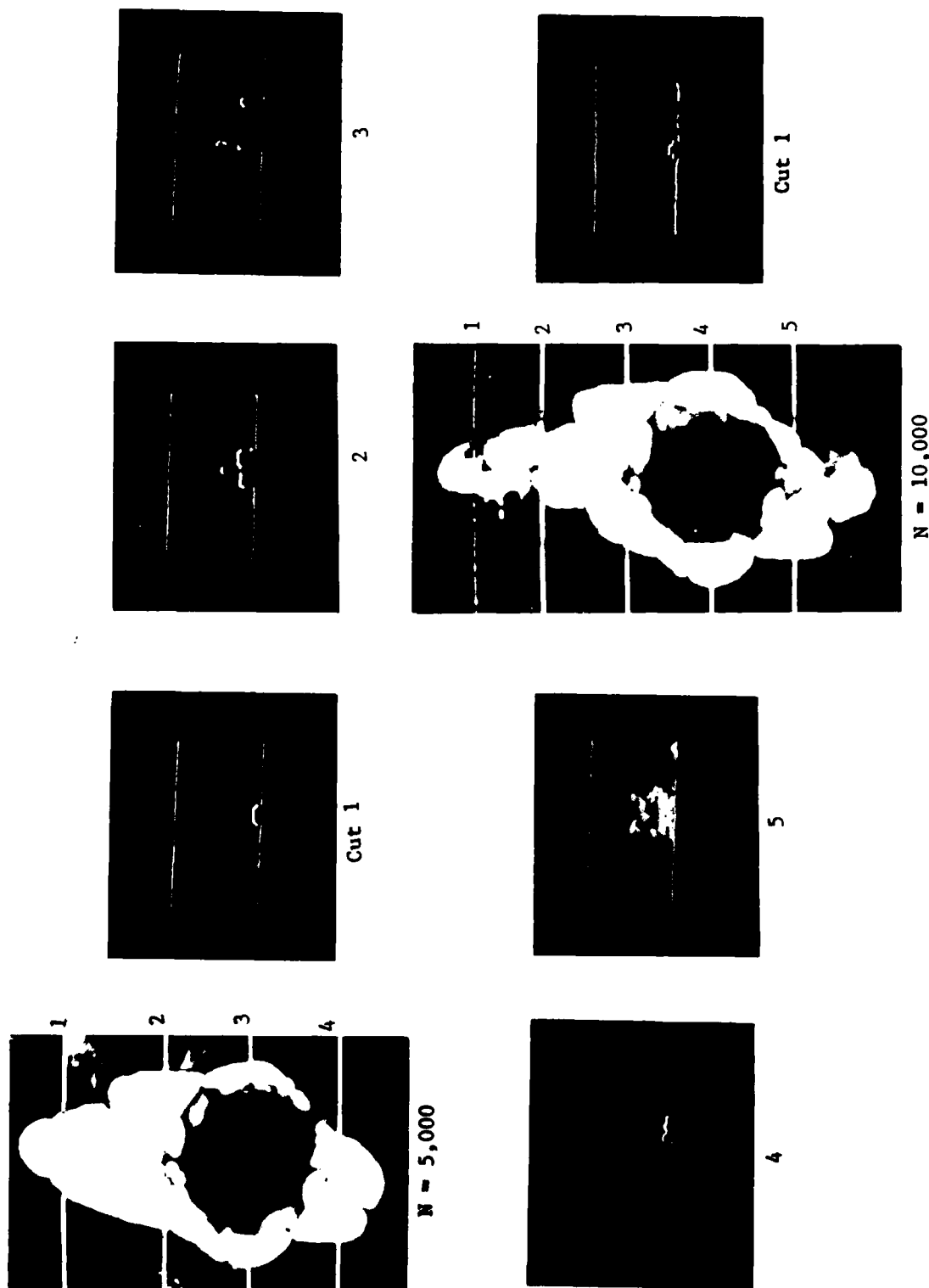


Figure D8b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, $N_f = 58,005$)

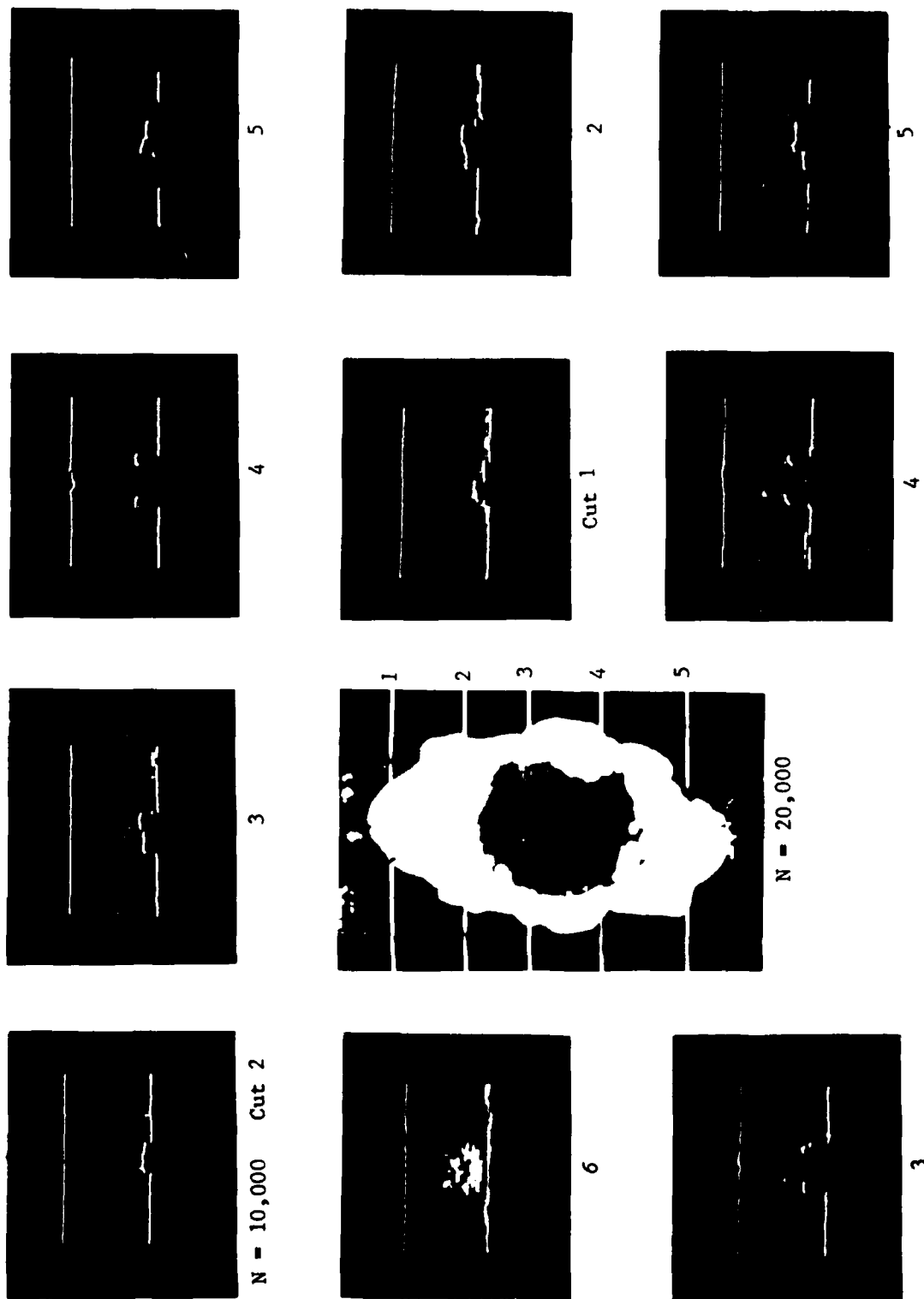


Figure D8c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, $N_f = 58,005$)

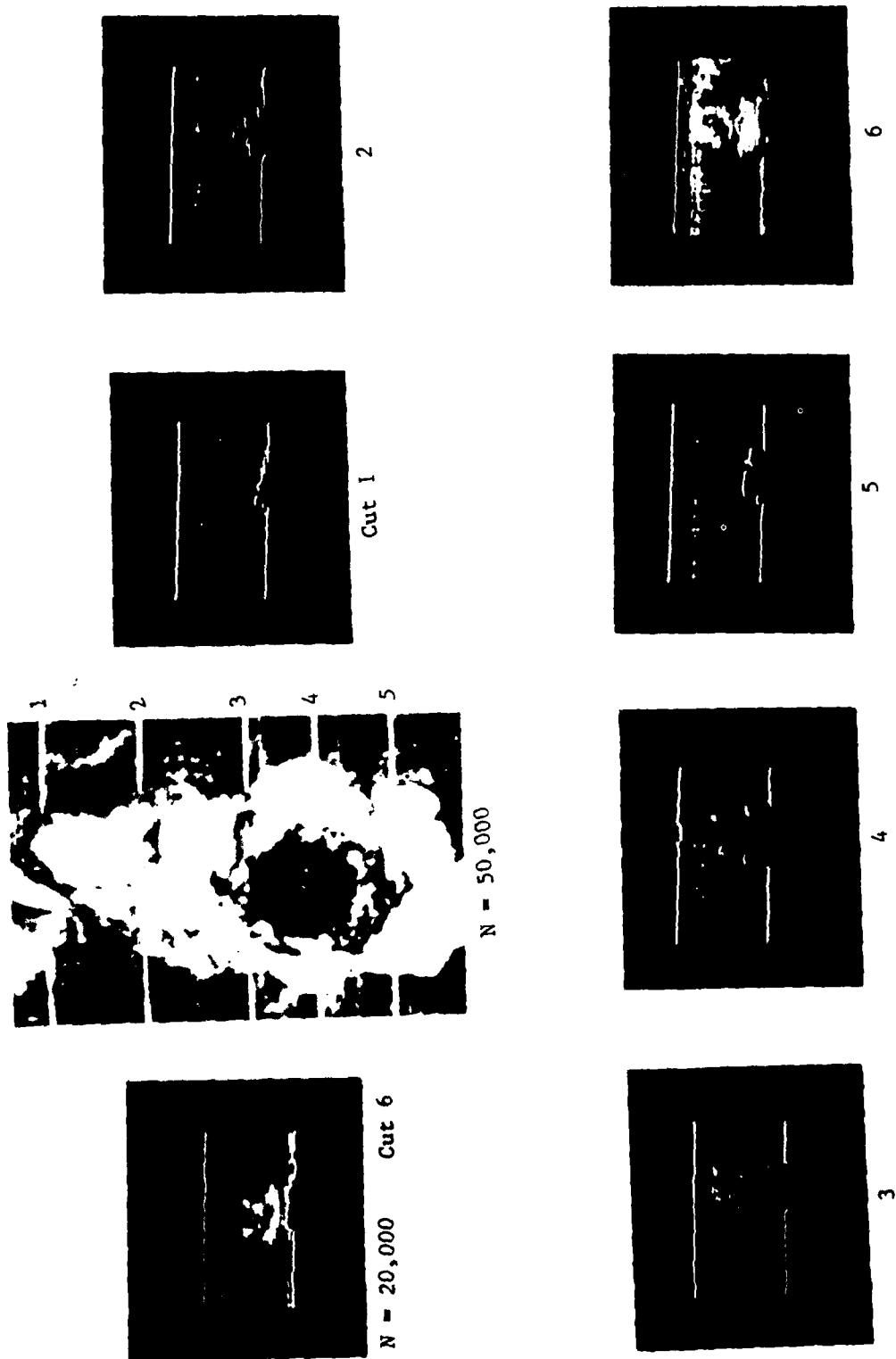


Figure D8d: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition A, 4-Bar Support (EB-18, $N_f = 58,005$)

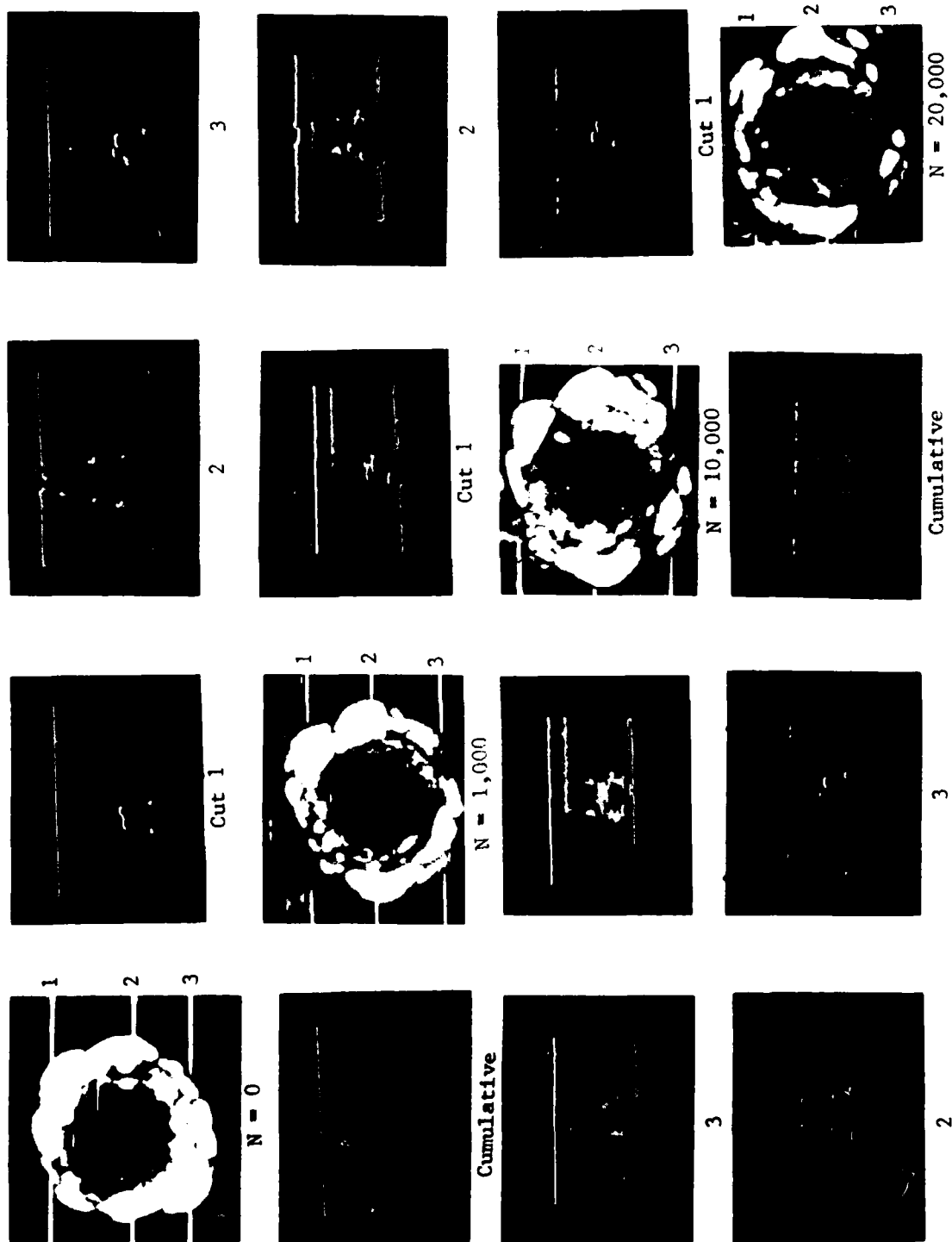


Figure D9a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, $R = -0.3$ ($EA-8$, 12×10^6 without failure)

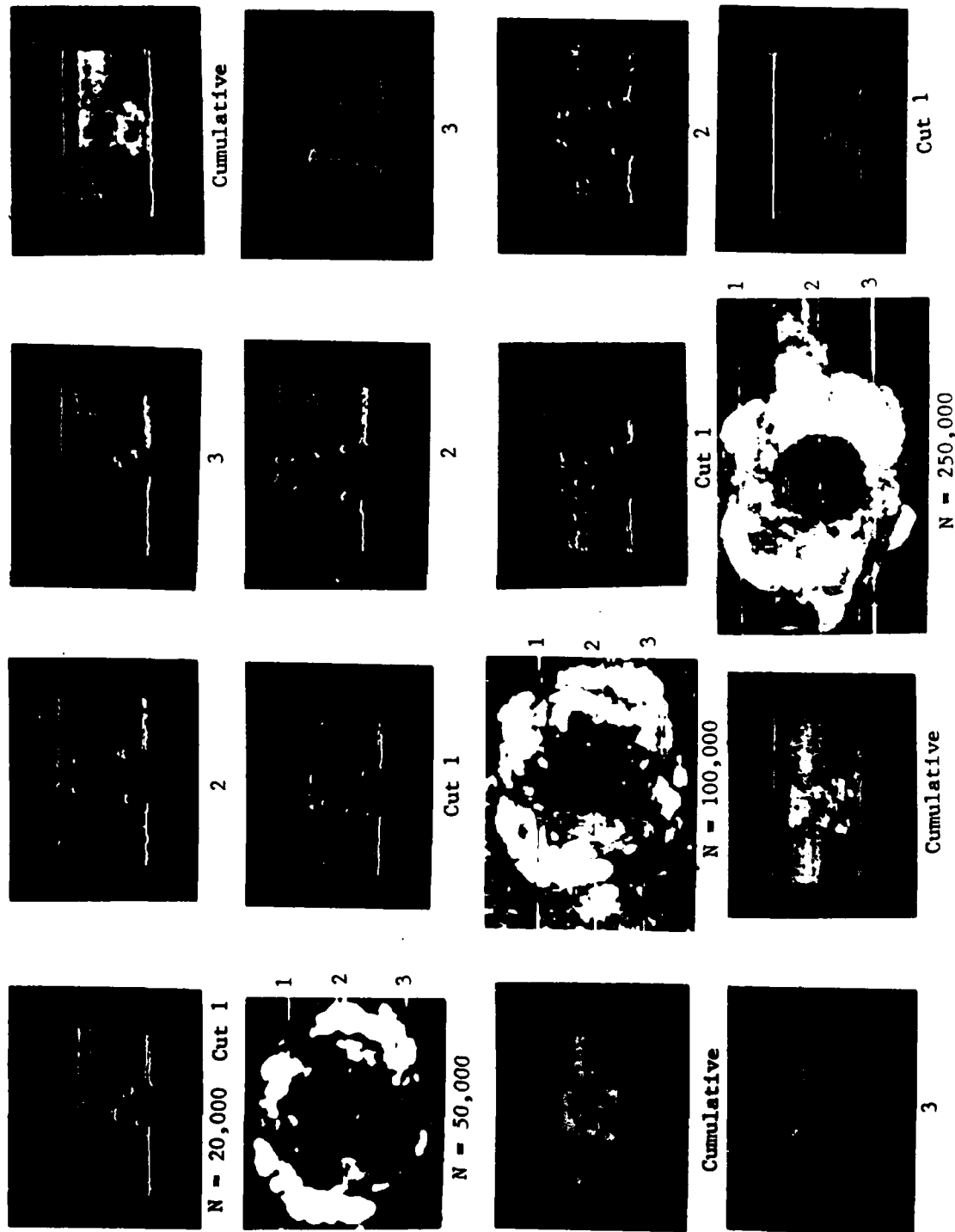


Figure D9b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, $R = -0.3$ (EA-8, 12×10^6 without failure)

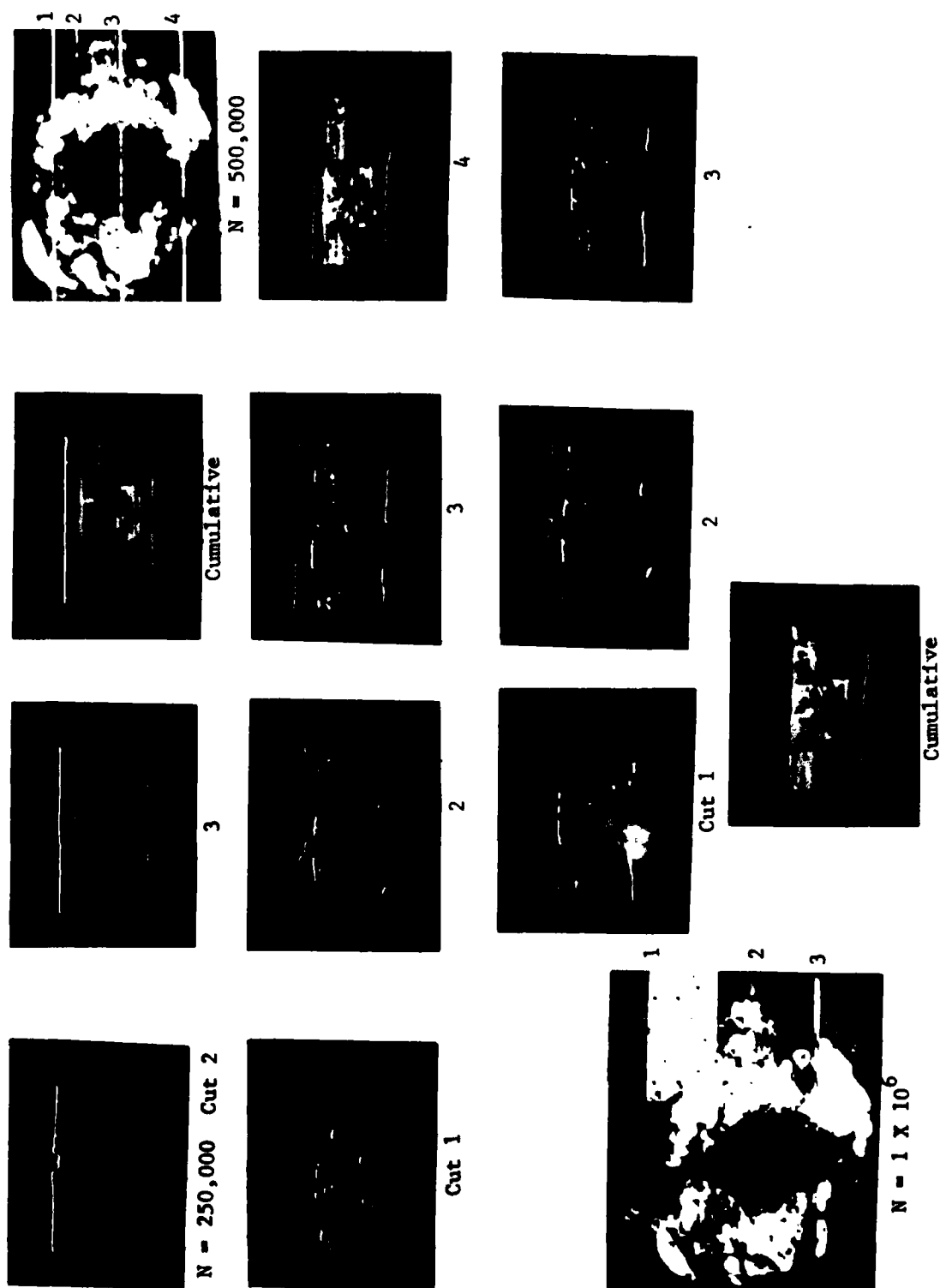


Figure D9c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, $R = -0.3$ (EA-8, 12×10^6 without failure)

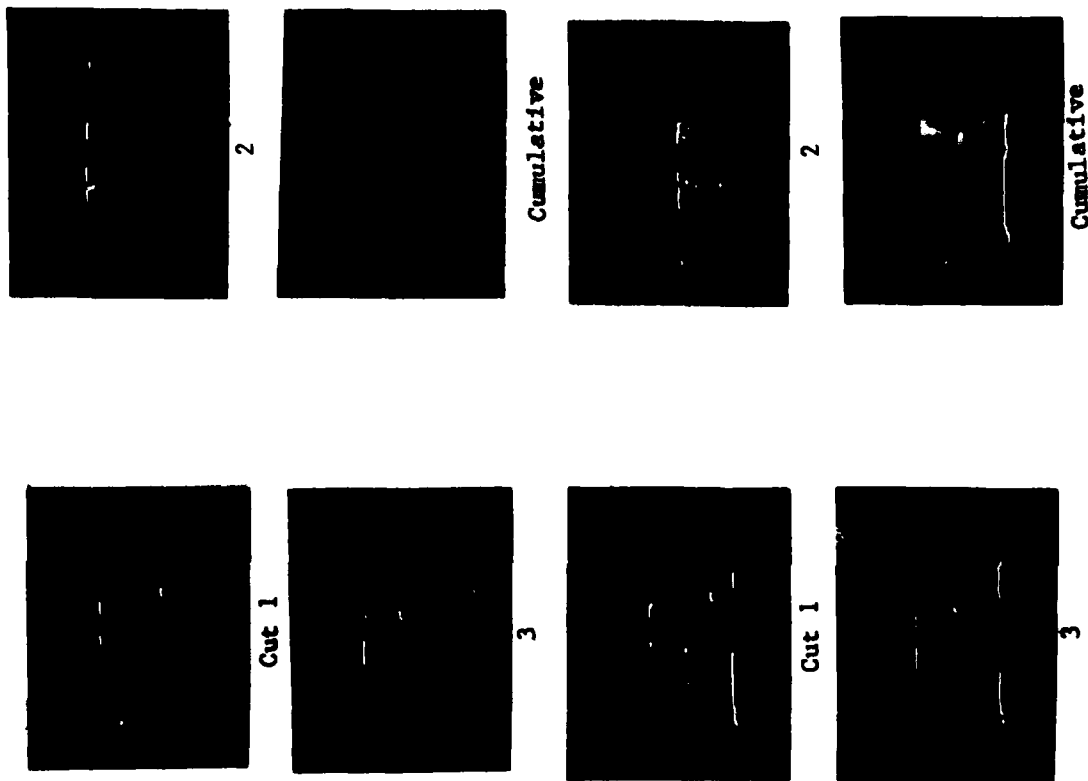


Figure D9d: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition B, $R = -0.3$ (EA-8, 12×10^6 without failure)

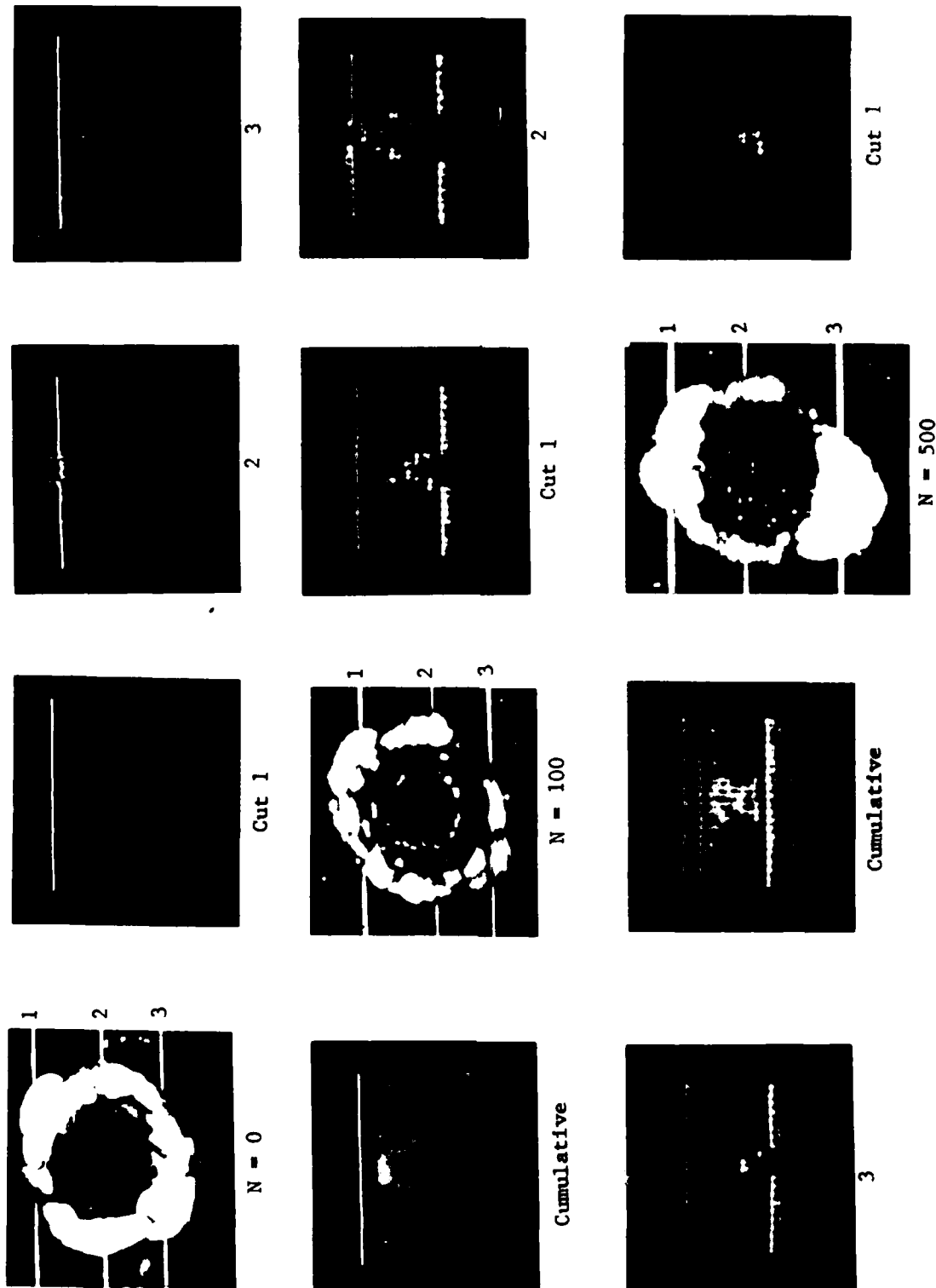


Figure D10a: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, $N_f = 72,420$)

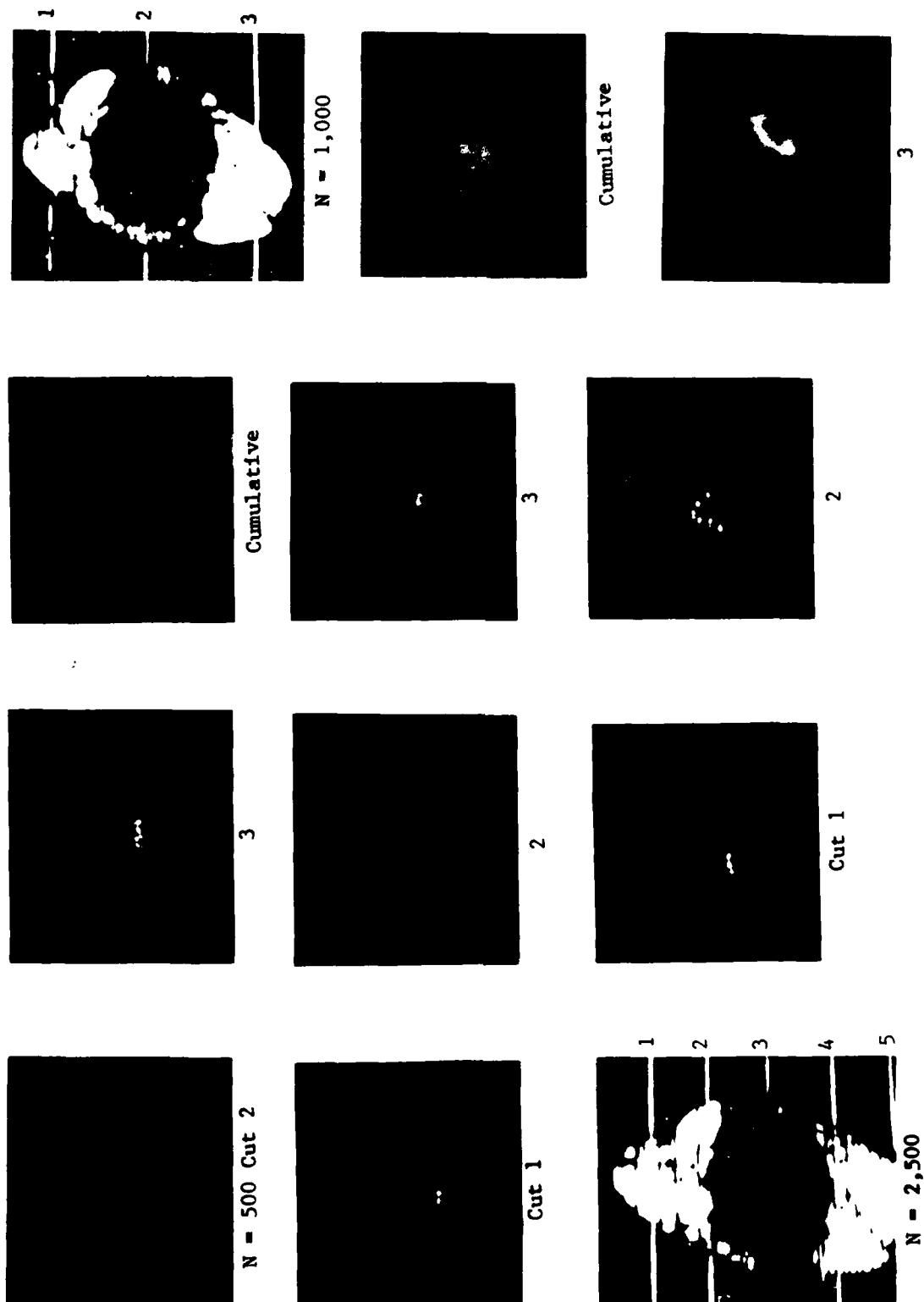


Figure D10b: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, $N_f = 72,420$)

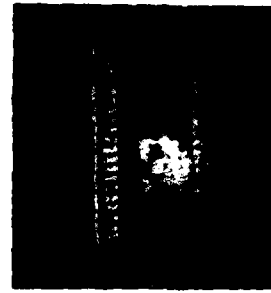
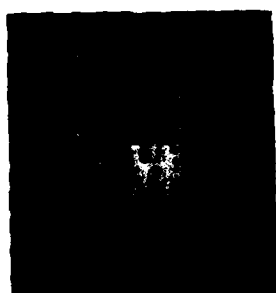
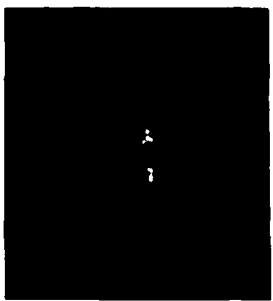


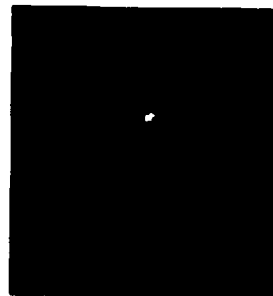
Figure D10c: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, $N_f \approx 72,420$)



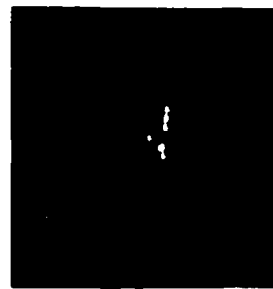
N = 10,000 Cut 1



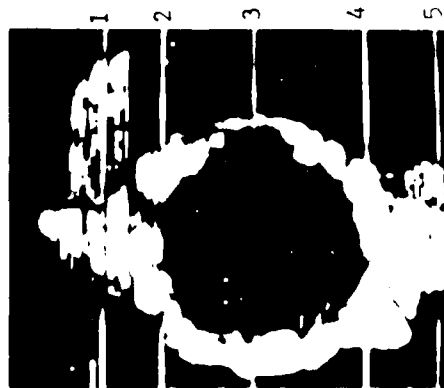
2



3



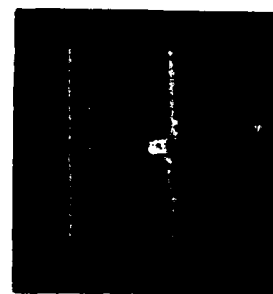
4



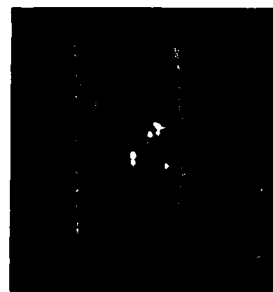
N = 20,000

Figure D10d:

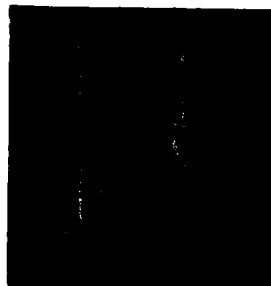
Damage Growth Characteristics of the 32-Ply Laminate for
Fatigue Condition C, 180°F (82°C) (DC-28, $N_f = 72,420$)



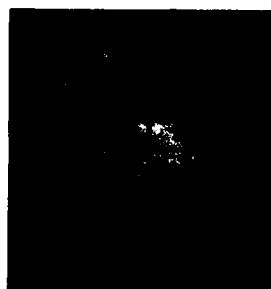
Cut 1



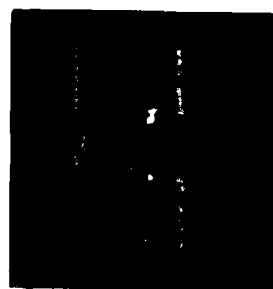
2



5



Cumulative



3

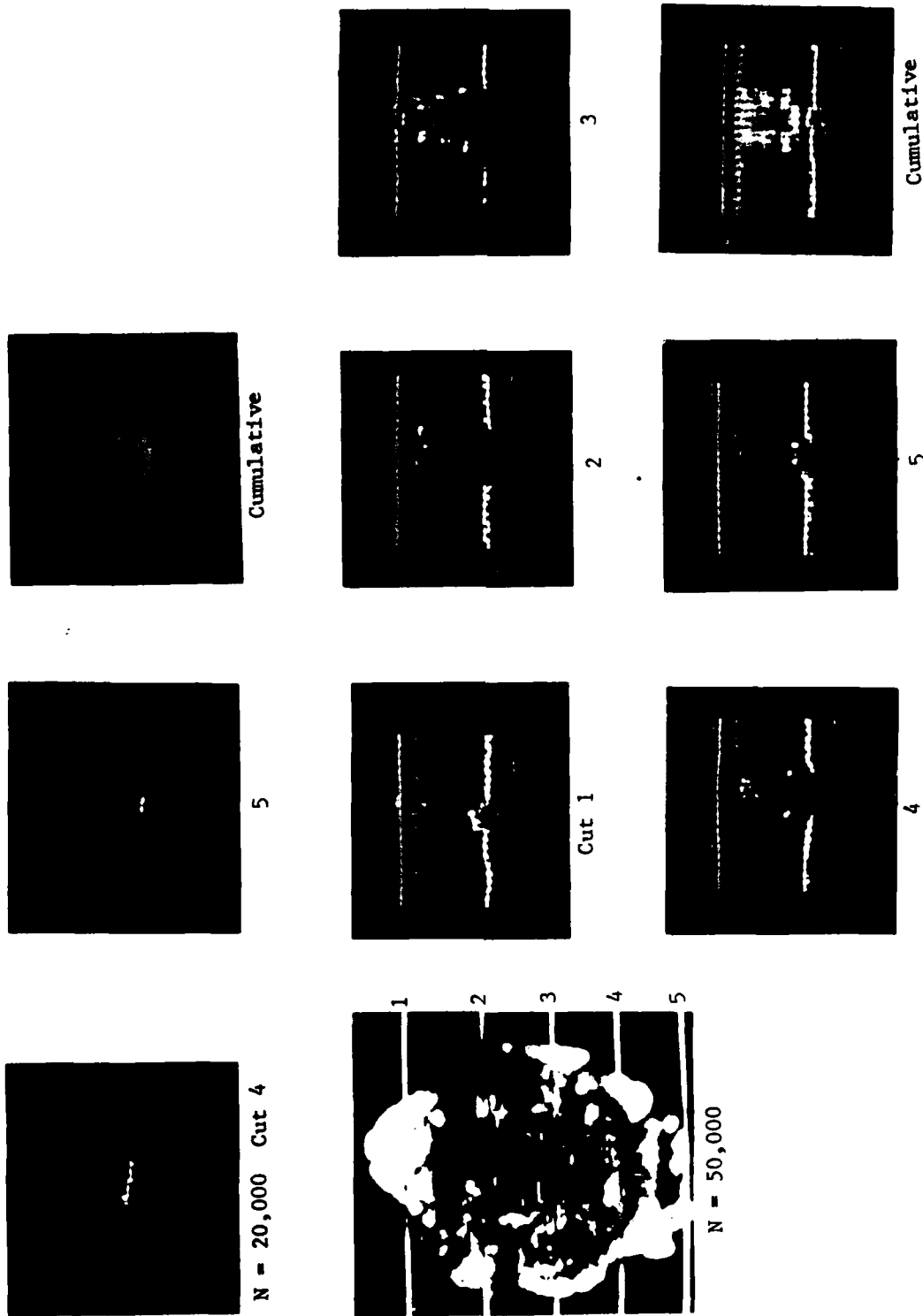


Figure D10e: Damage Growth Characteristics of the 32-Ply Laminate for Fatigue Condition C, 180°F (82°C) (DC-28, $N_f = 72,420$)

APPENDIX E

Damage Characteristics of Specimens
Tested for Residual Strength

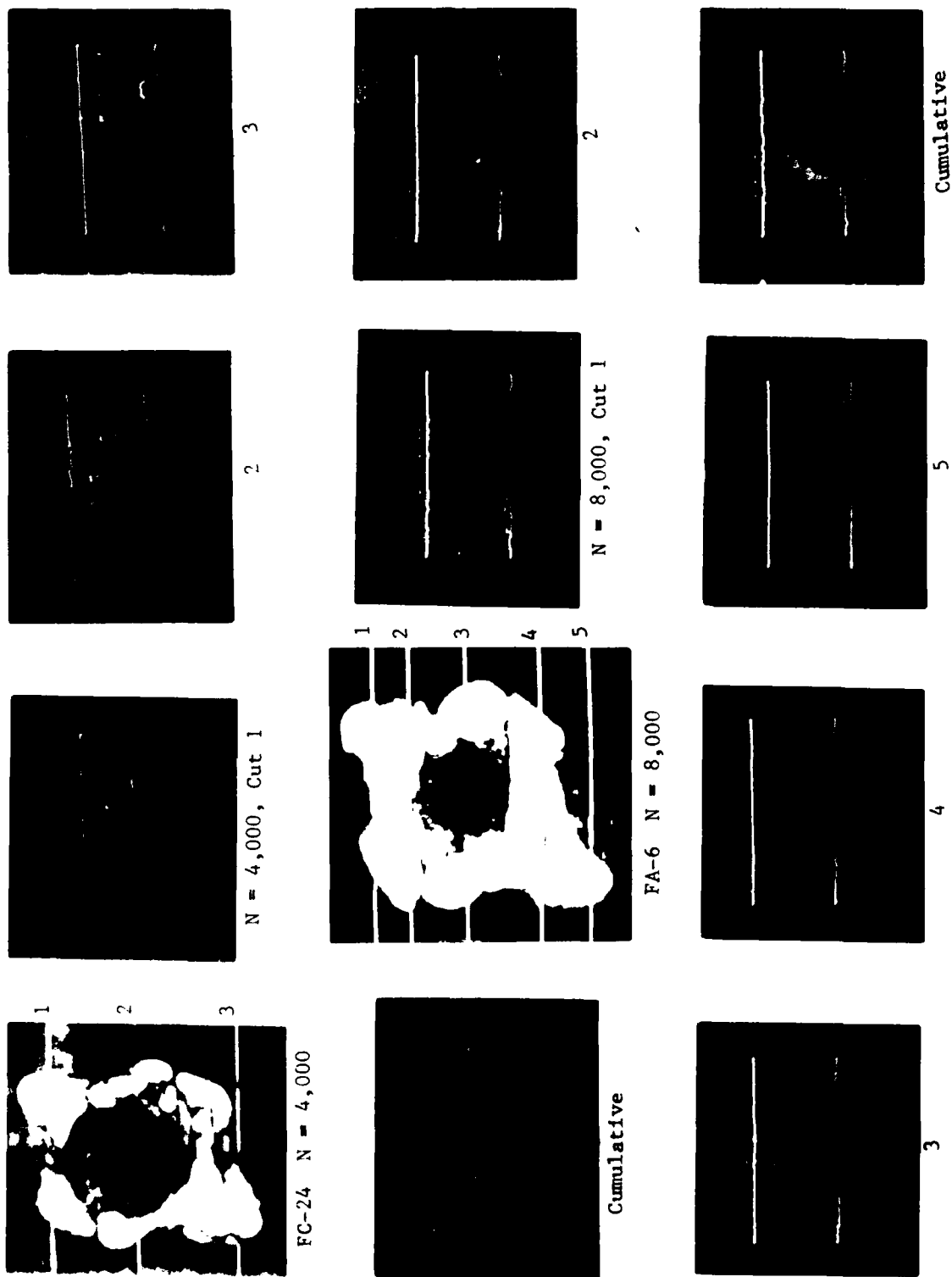


Figure E1a: Damage Characteristics of 24-Ply Specimens Fatigue Cycled at ± 35 ksi (± 241 MPa) for Residual Strength Determination

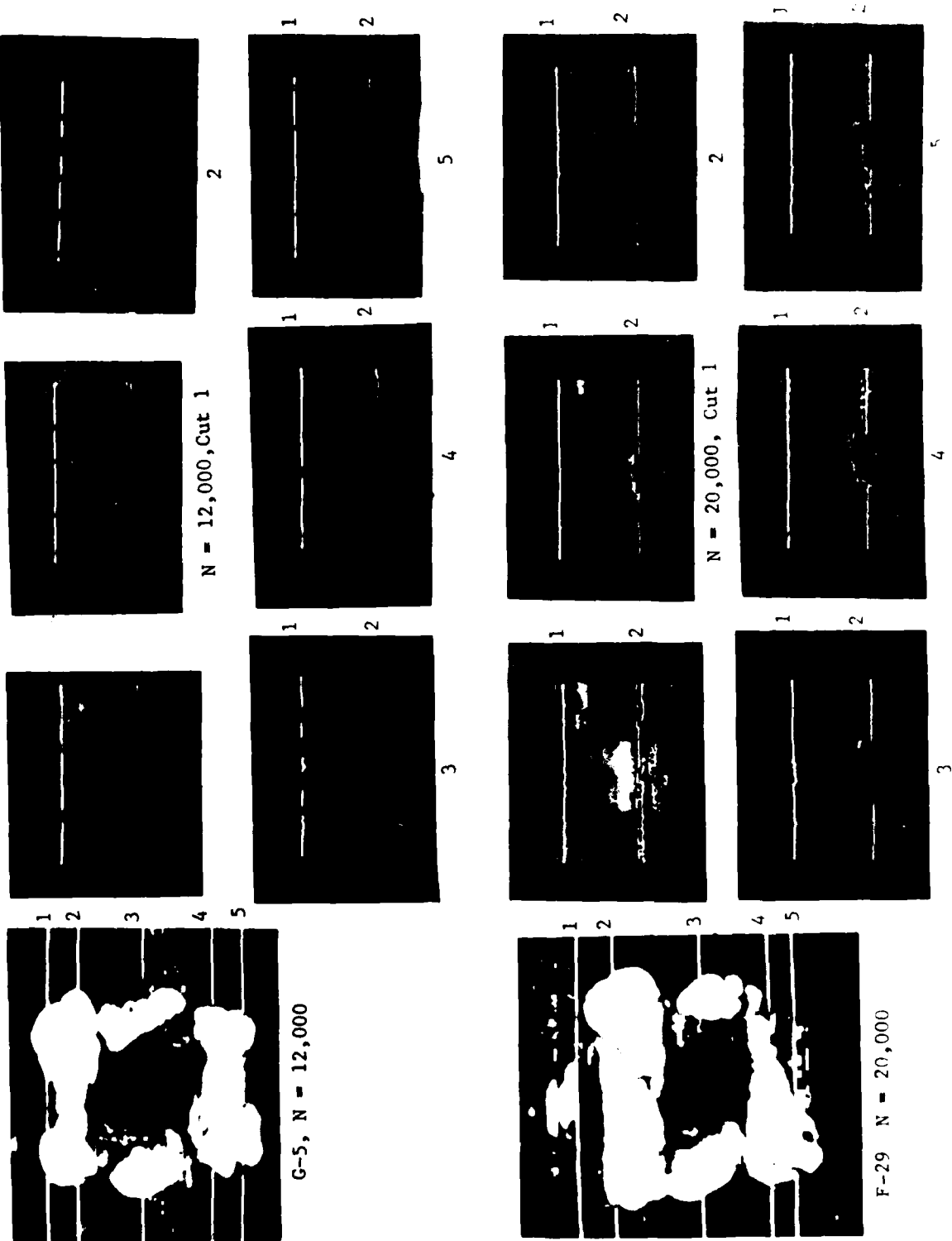


Figure E1b: Damage Characteristics of 24-Ply Specimens Fatigue Cycled at +35 ksi (+241 MPa) for Residual Strength Determination

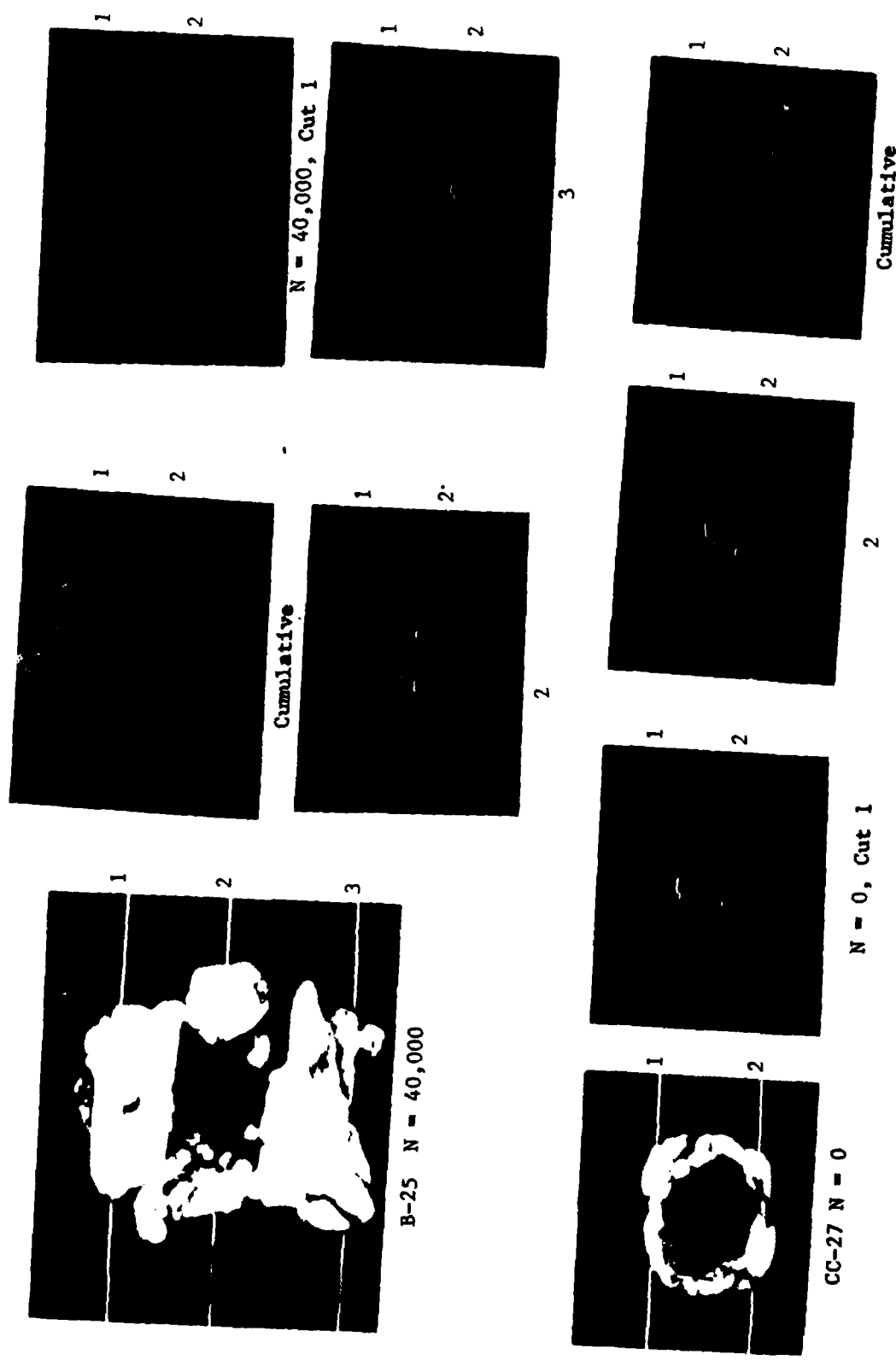


Figure E1c: Damage Characteristics of 24-ply Specimens Fatigue Cycled at ± 35 ksi (± 241 MPa) for Residual Strength Determination

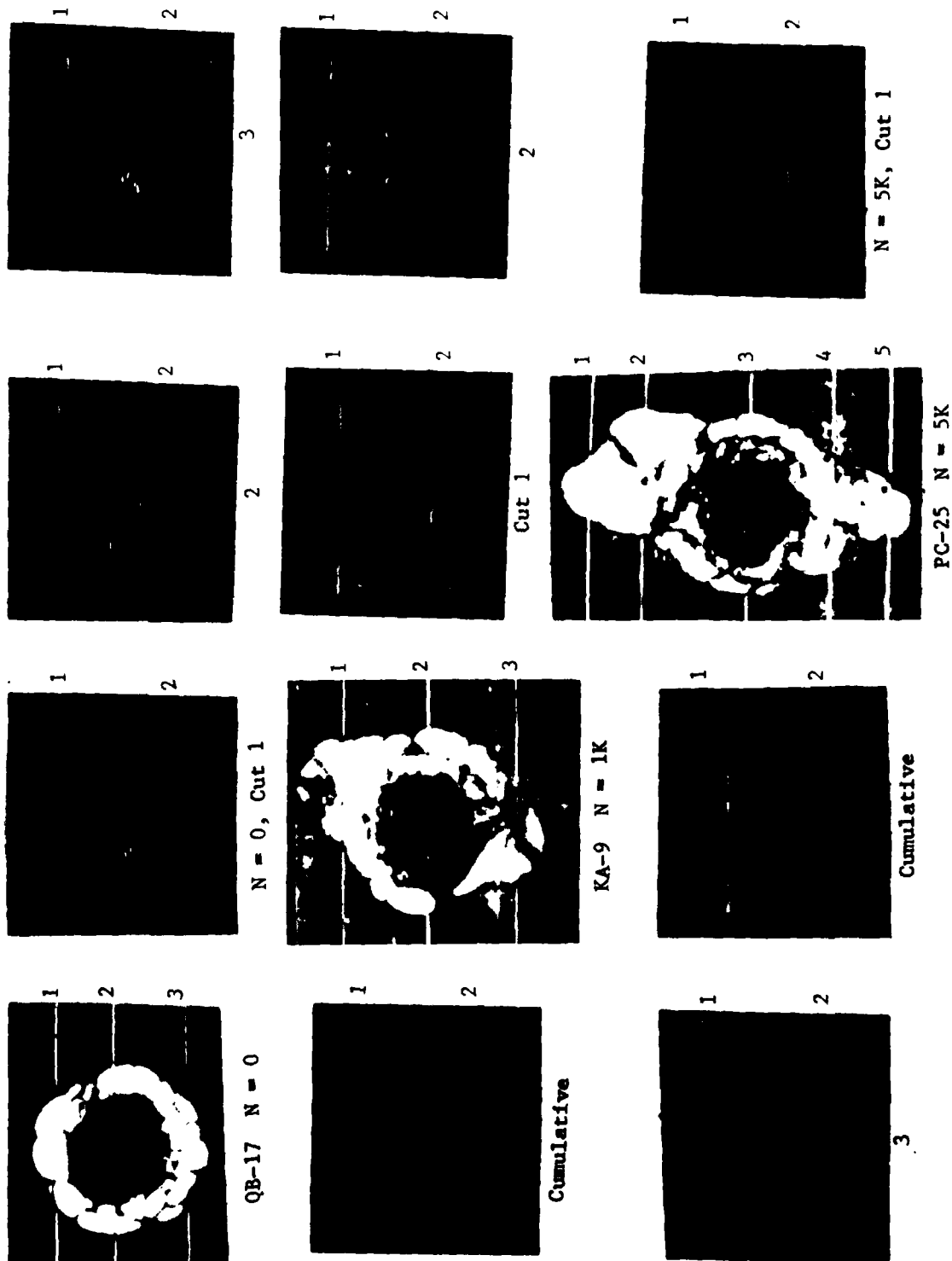


Figure E2a: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at +22 ksi (152 MPa) for Residual Strength Determination

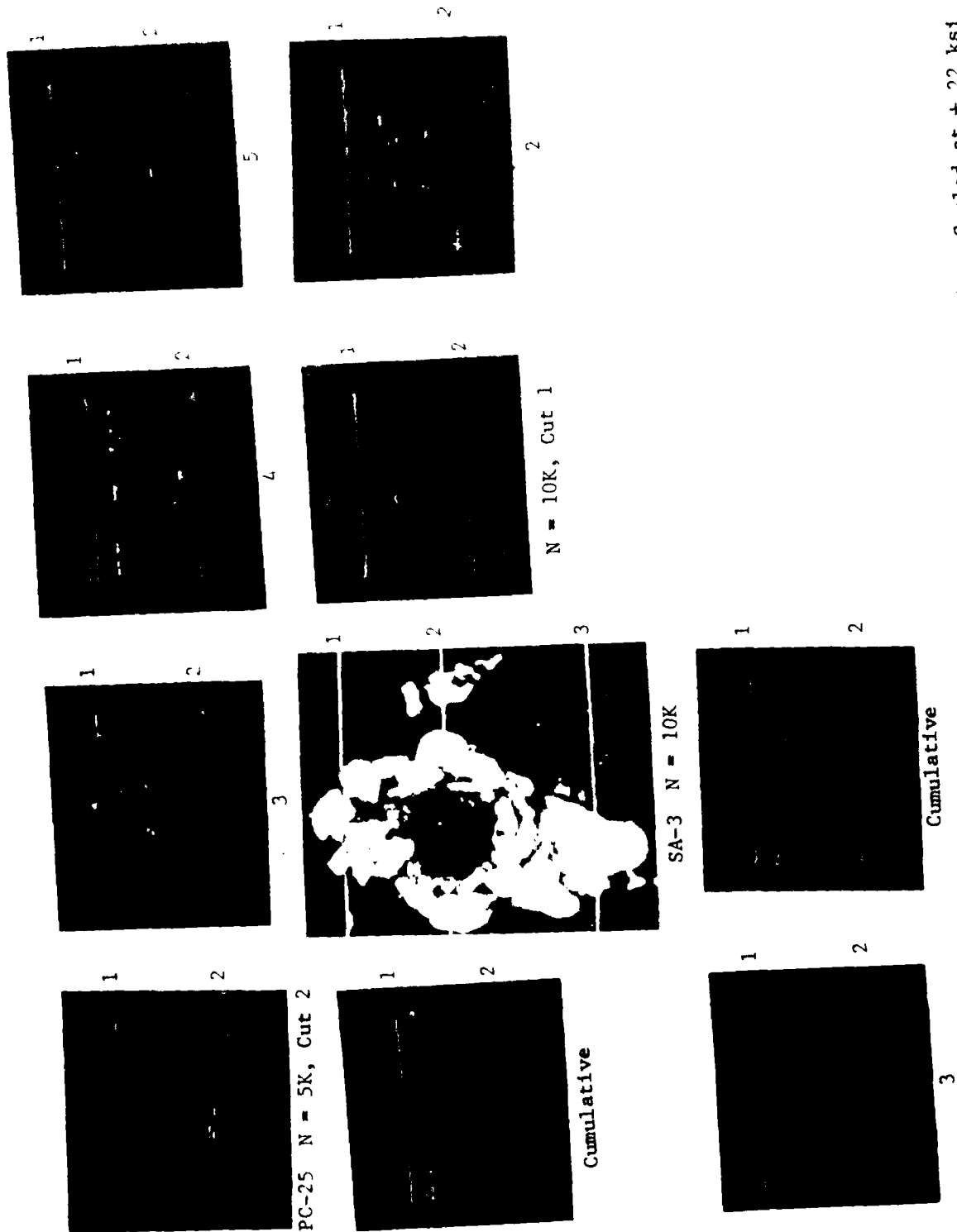


Figure E2b: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at ± 22 ksi (± 152 MPa) for Residual Strength Determination

Figure E2c: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at ± 22 ksi (± 152 MPa) for Residual Strength Determination



J-23 N = 28K



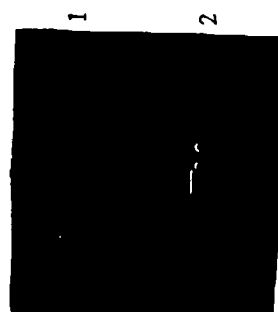
N = 28K, Cut 1



2



3



4



5



Cumulative

Figure E2d: Damage Characteristics of 32-Ply Specimens Fatigue Cycled at ± 22 ksi (± 152 MPa) for Residual Strength Determination

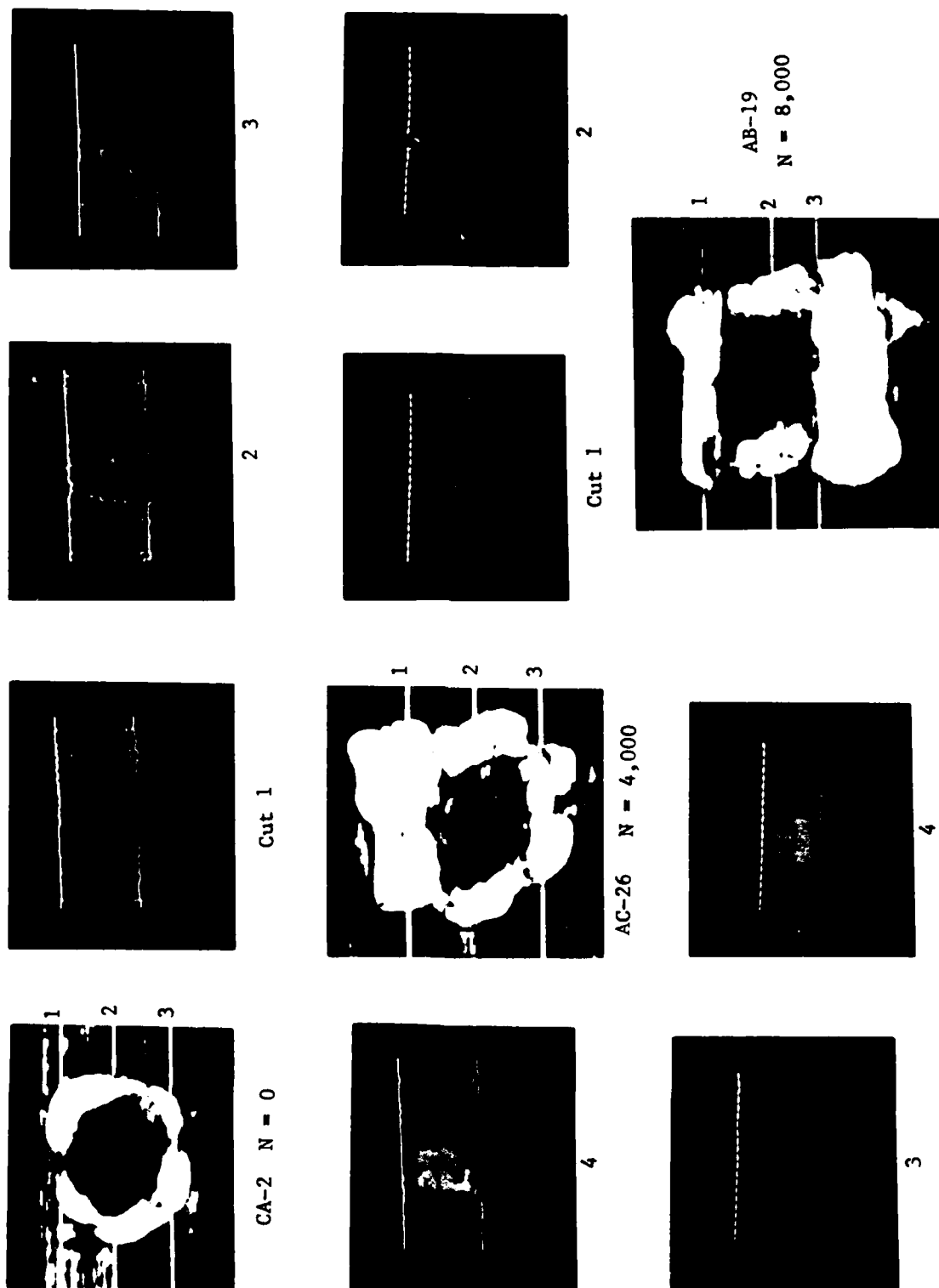


Figure E3a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under Fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

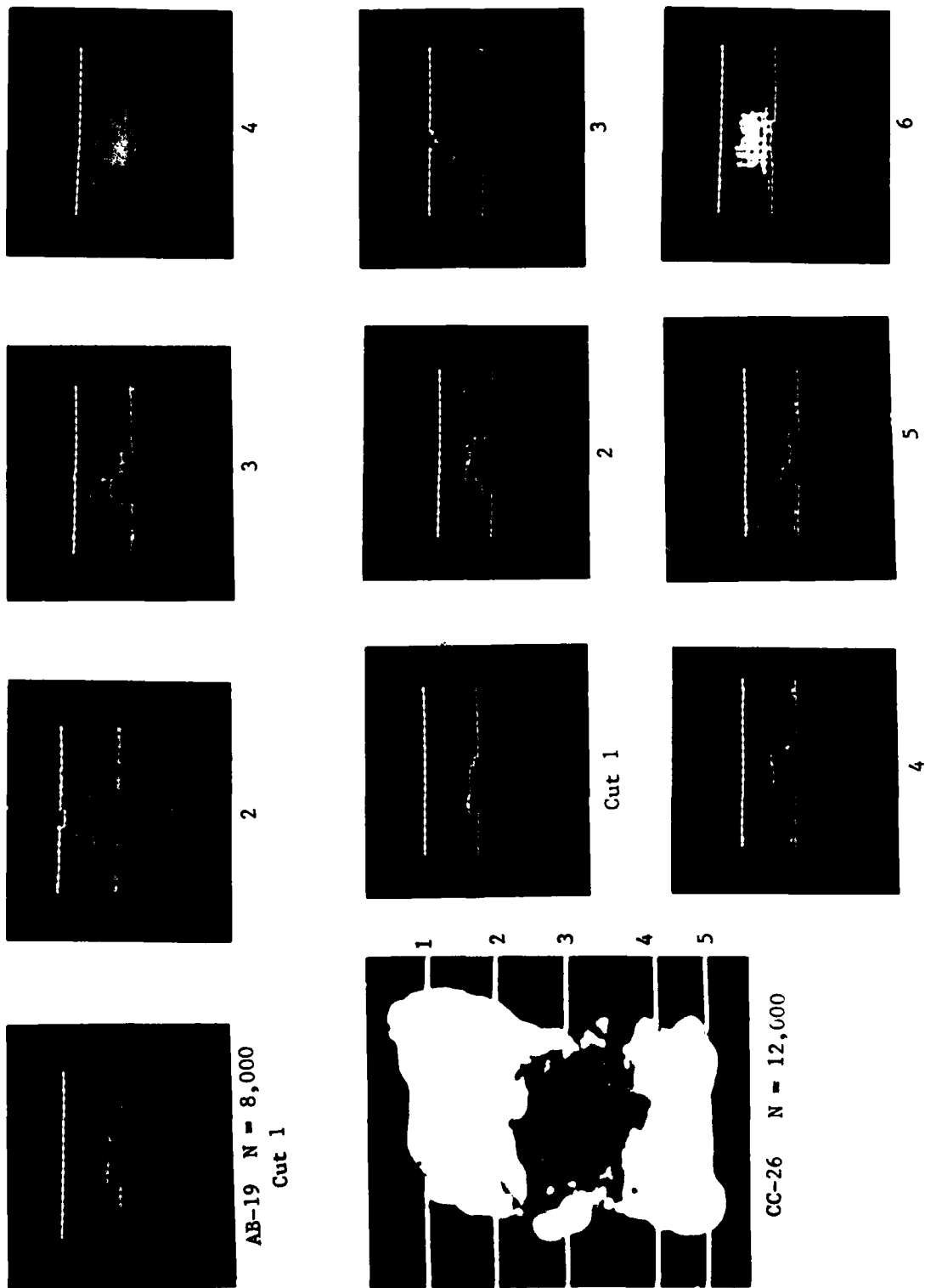


Figure E3b: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

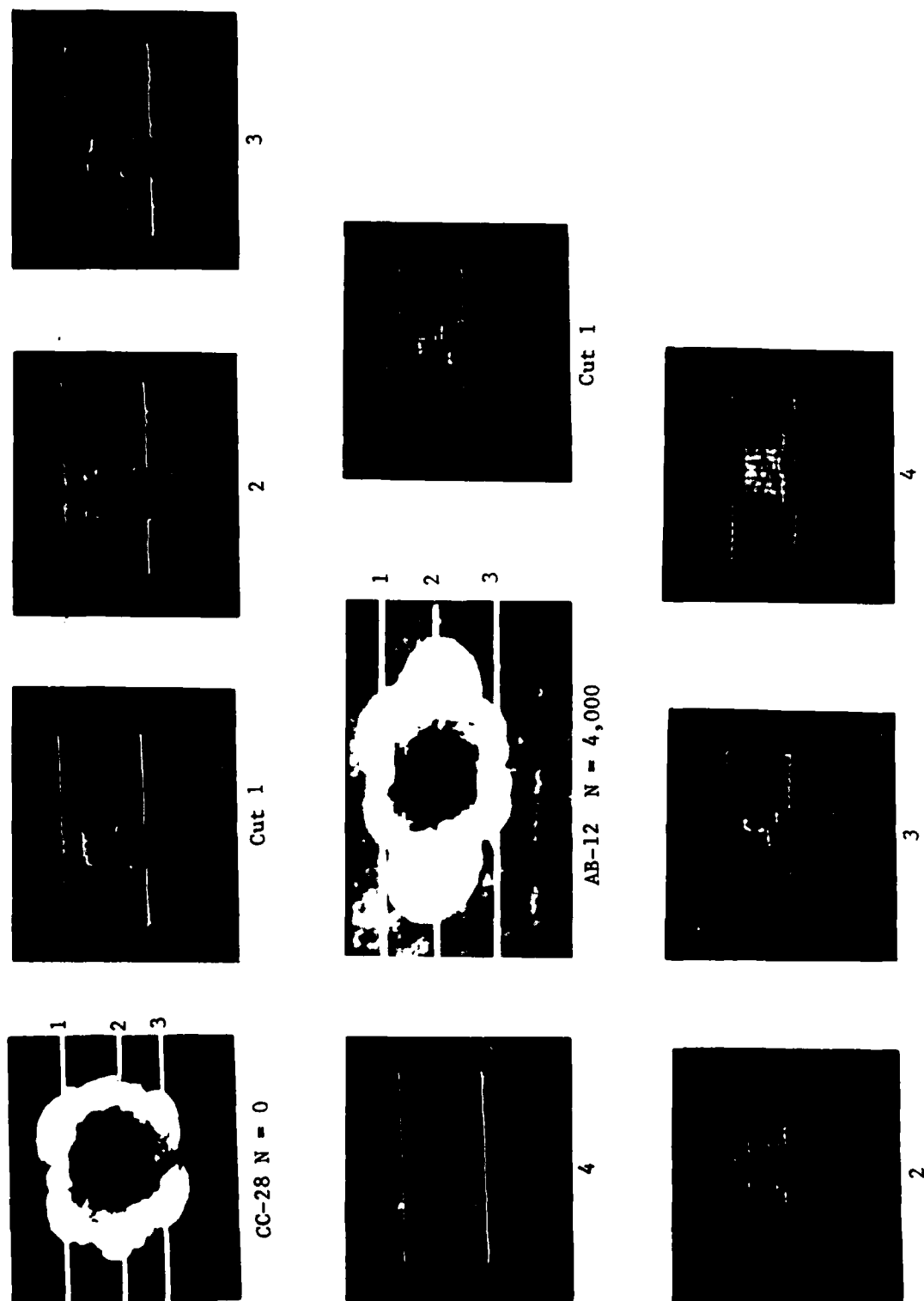


Figure E4a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, $R = -0.3$ (See Table XXXV, Vol. II)

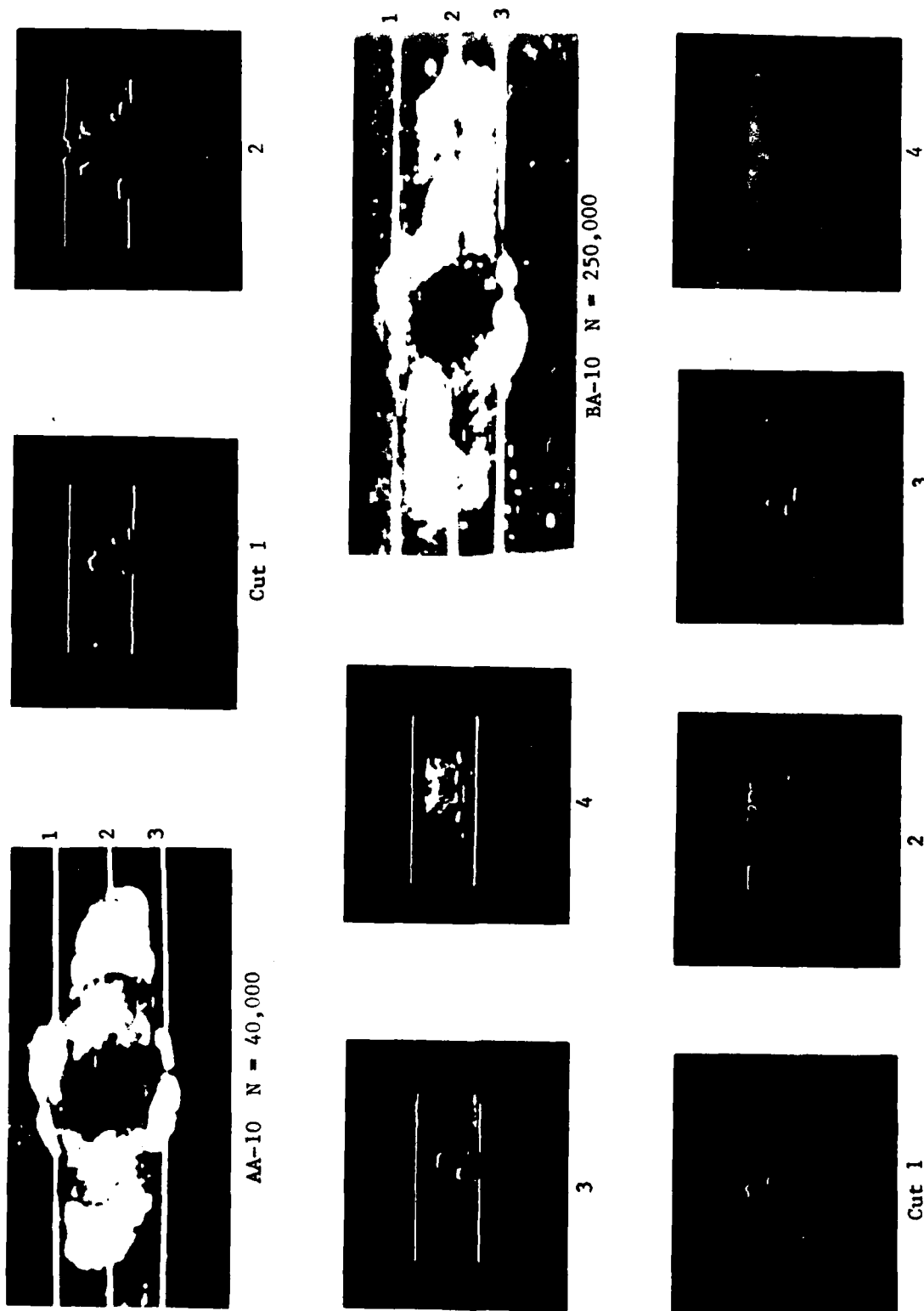


Figure E4b: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, $R = -0.3$ (See Table XXXV, Vol. II)

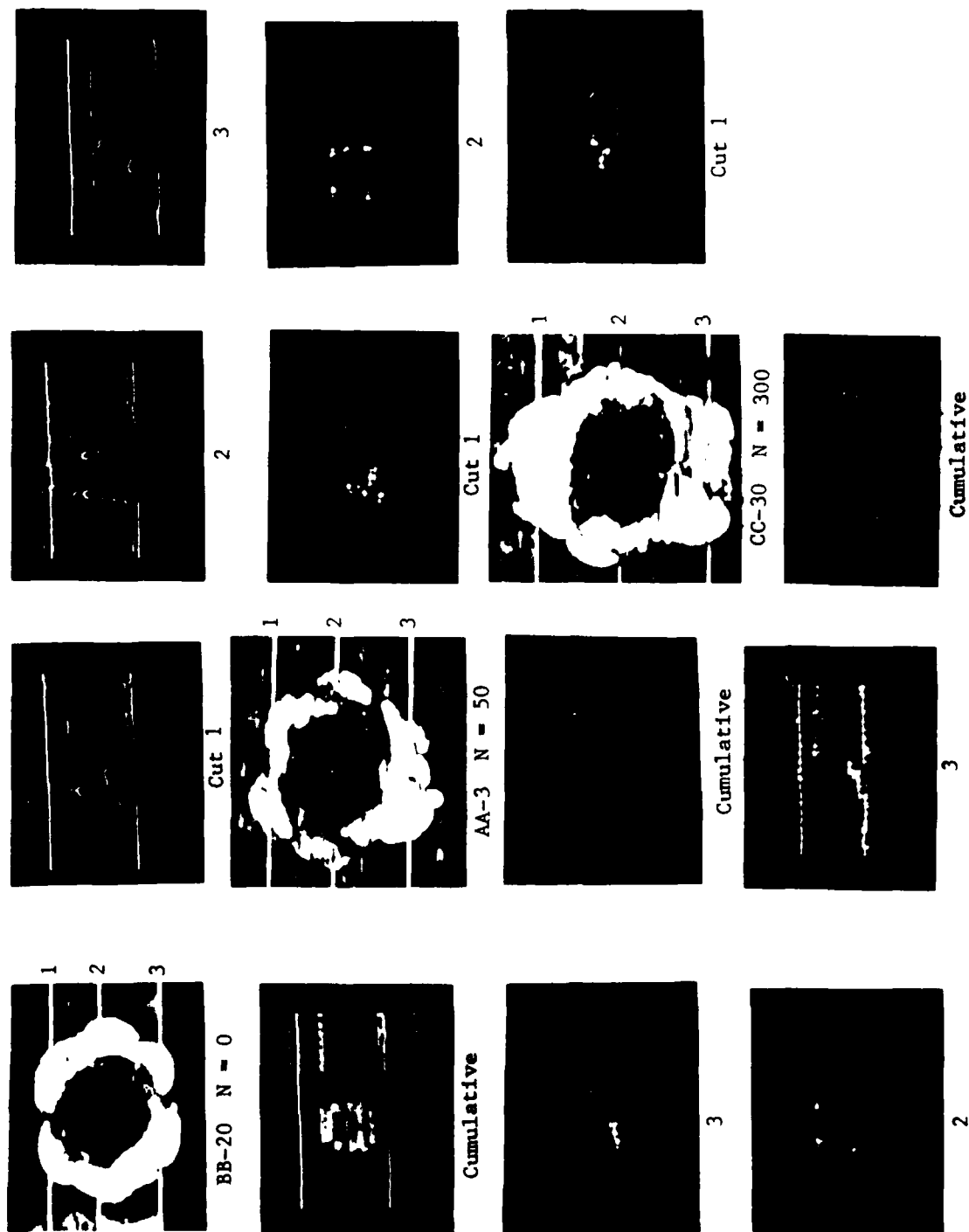


Figure E5a: Damage Characteristics of 24-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180°F (82°C) (See Table XXXV, Vol. II)

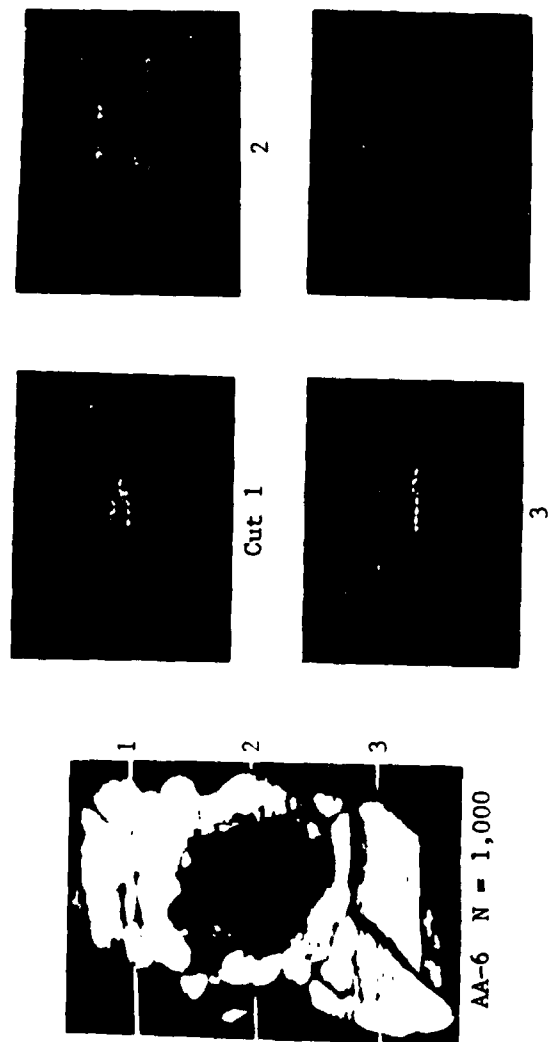


Figure E5b: Damage Characteristics of 24-Ply Specimens Cycled for
Residual Strength Determination Under fatigue Condition C,
180°F (82°C) (See Table XXV, Vol II)

AA-6 N = 1,000

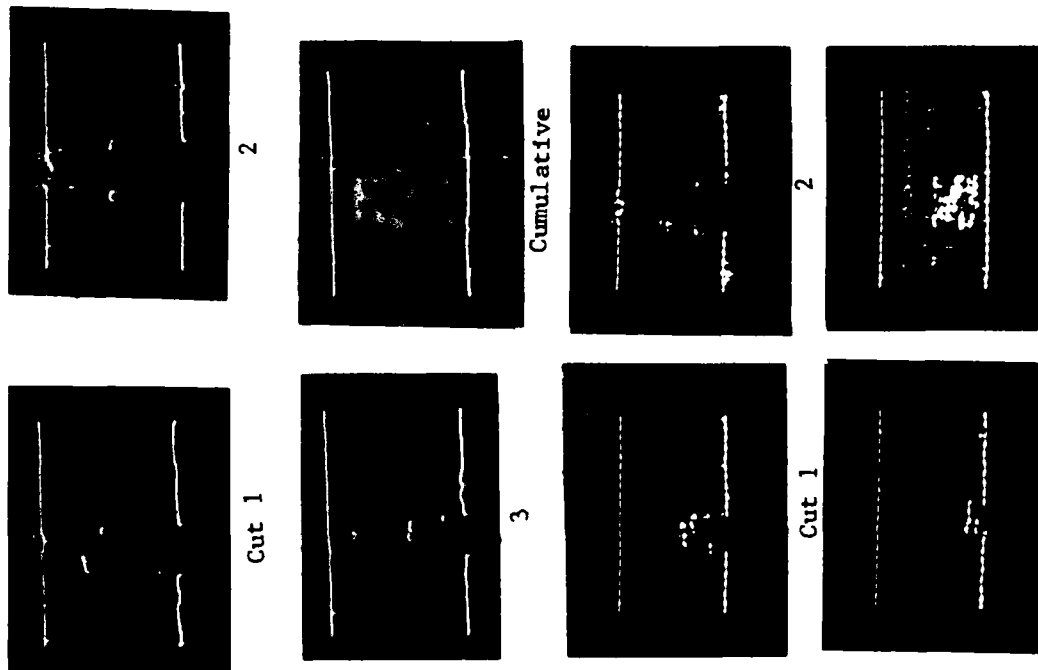
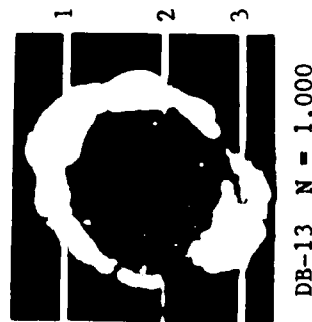
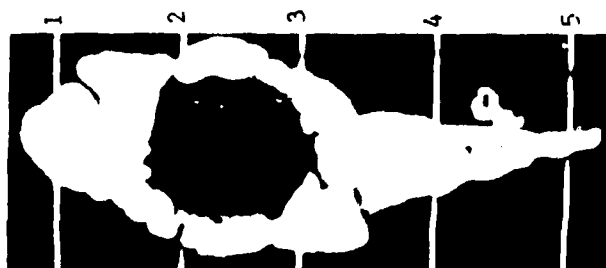
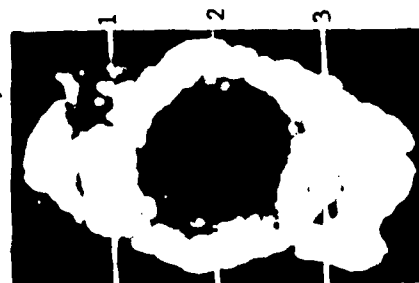


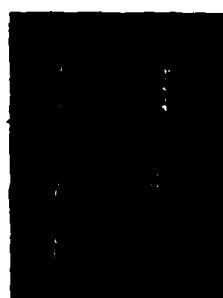
Figure E6a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXV, Vol. II)



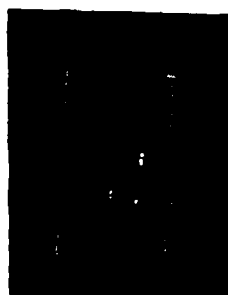
EA-7 N = 10,000



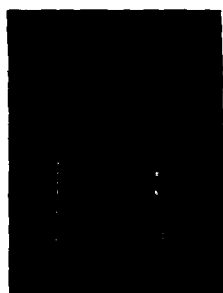
DB-11 N = 20,000



Cut 1



4



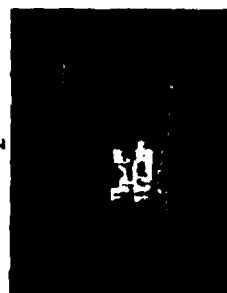
2



5



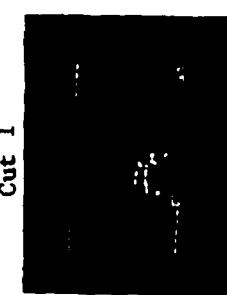
2



Cumulative



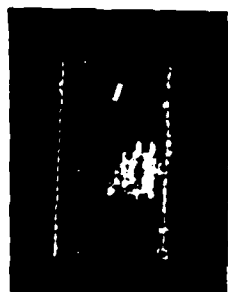
Cut 1



3



3



Cumulative

Figure E6b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition A, 4-Bar Support (See Table XXXV, Vol. II)

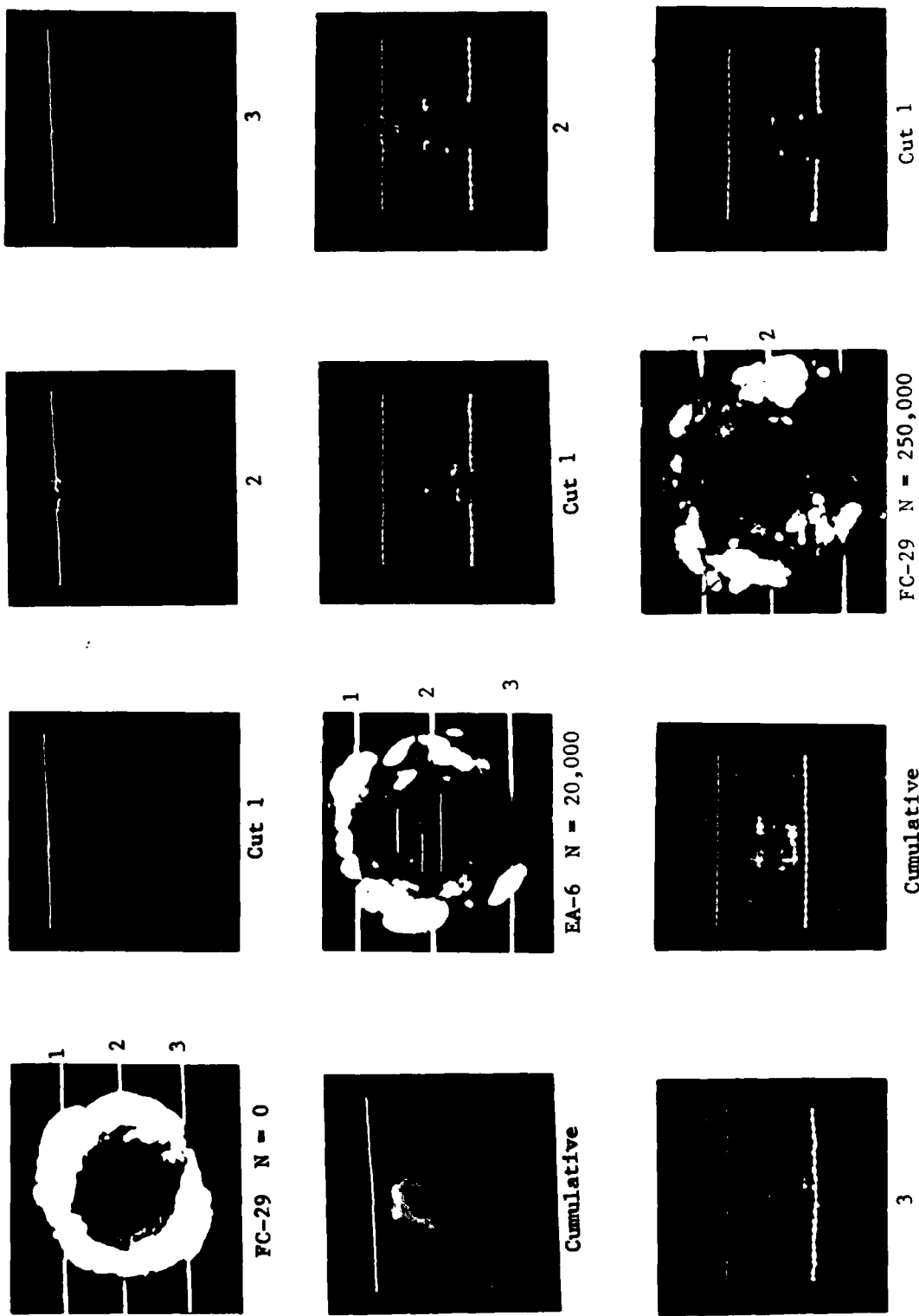


Figure E7a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B. $R = -0.3$ (See Table XXXV, Vol. II)

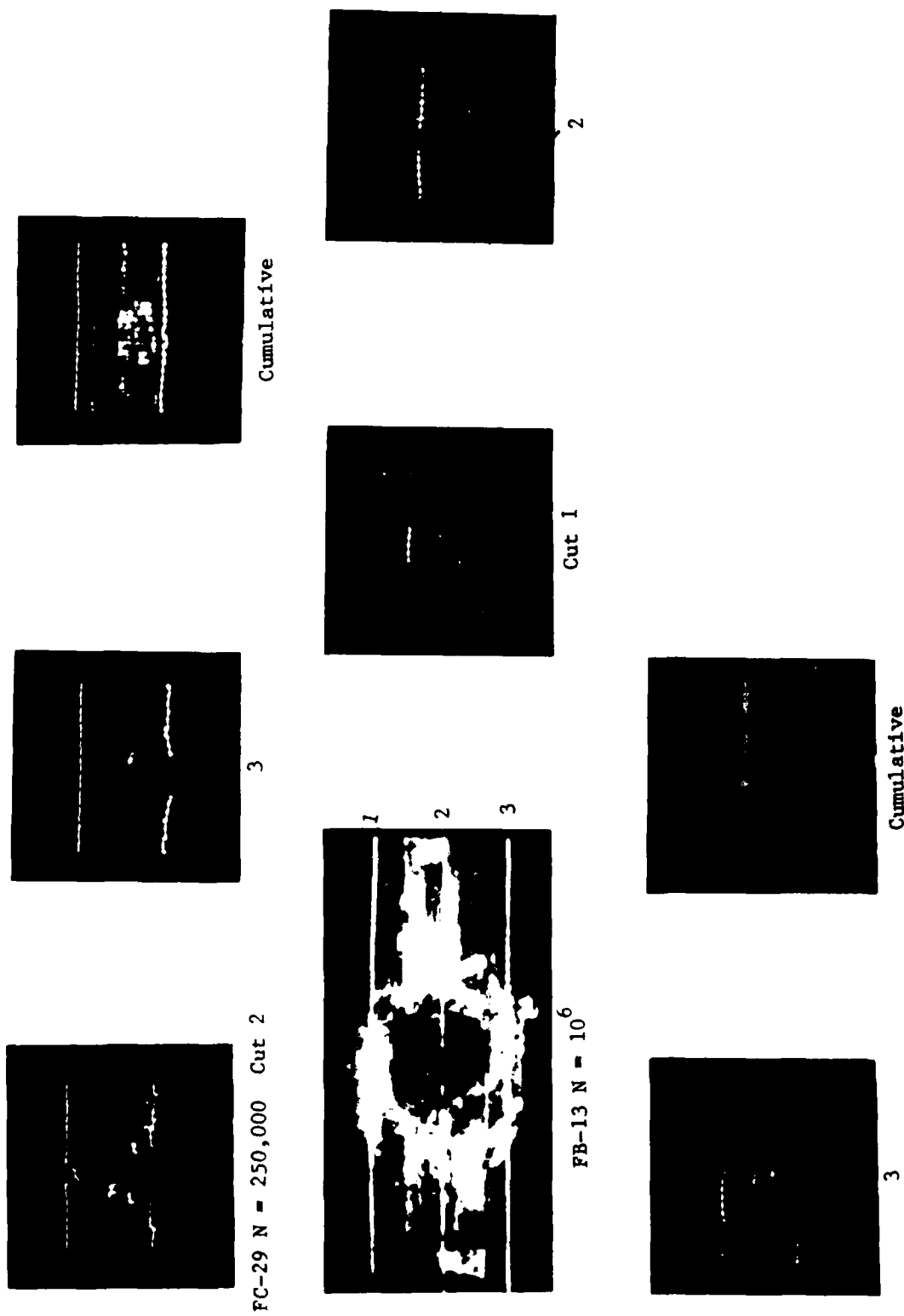


Figure E7b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition B, R = -0.3 (See Table XXV, Vol. II)

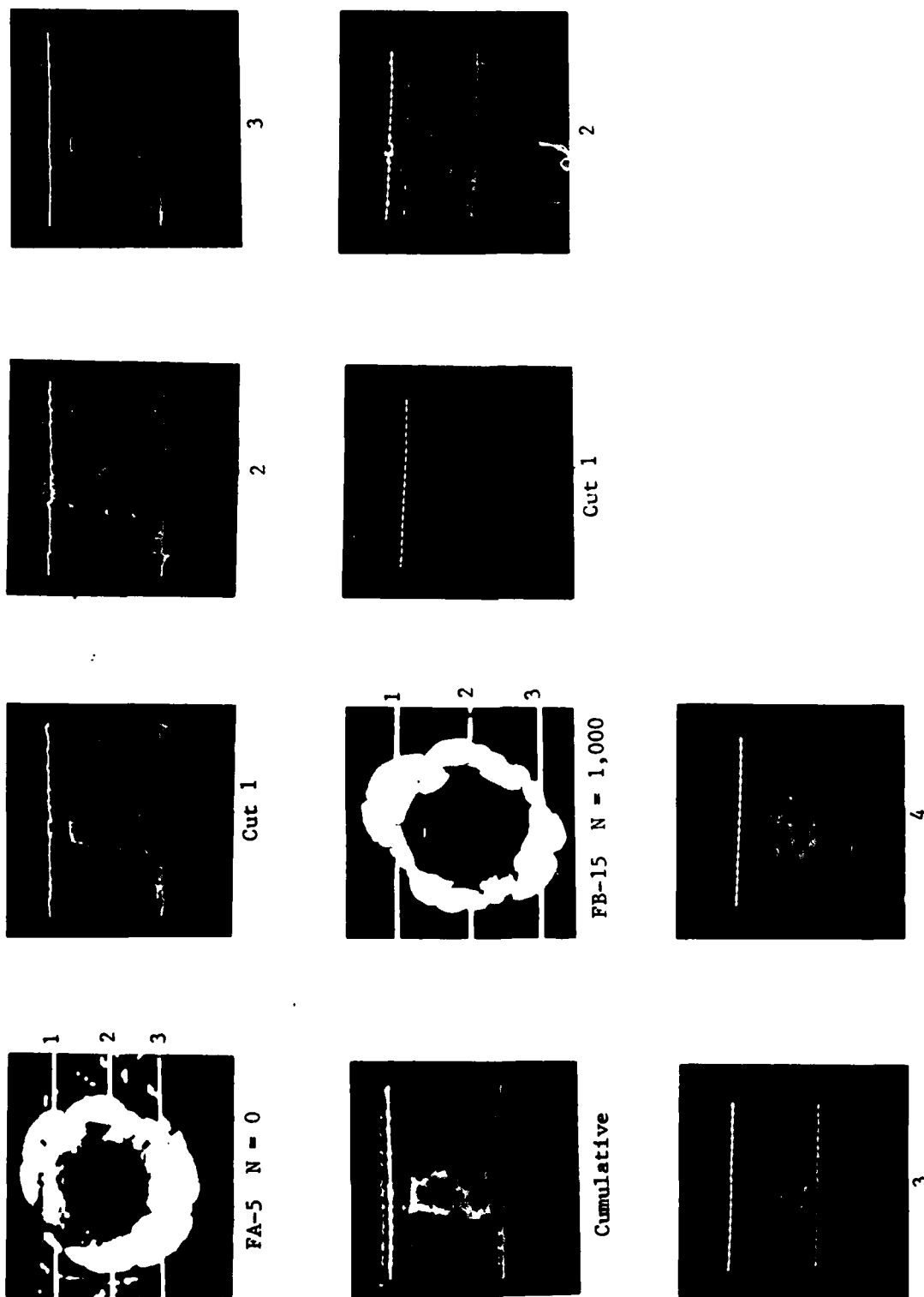
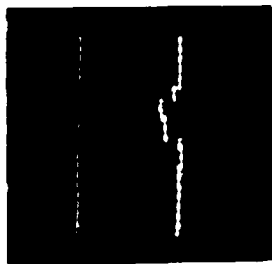


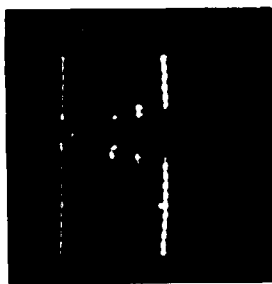
Figure E8a: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180 F (82 C) (See Table XXV, Vol. II)



DA-1 N = 4,000



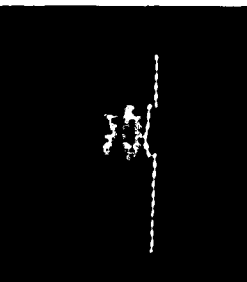
Cut 1



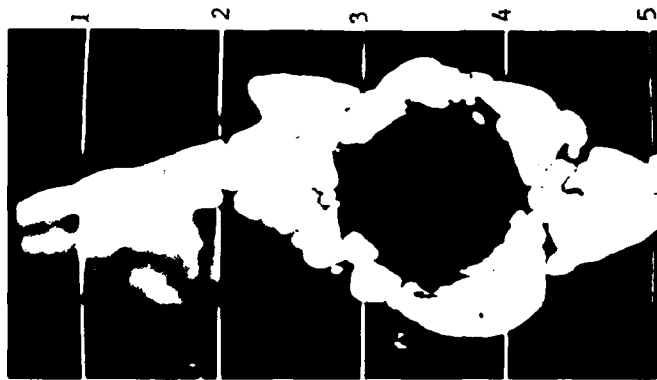
2



2



Cumulative



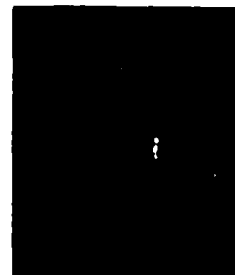
FC-27 N = 8,000



3



4



5

Cumulative

Figure E8b: Damage Characteristics of 32-Ply Specimens Cycled for Residual Strength Determination Under fatigue Condition C, 180° F (82° C) (See Table XXXV, Vol. II)

APPENDIX F

Damage Measurements of Specimens
Tested for Residual Strength

F1 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT
 $\pm 35\text{ksi}$ TO 4000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC. ID.	$N_o=0$			$N_1=4000$		
	WIDTH X,in.	LENGTH Y,in.	AREA A,in. ²	WIDTH X,in.	LENGTH Y,in.	AREA A,in. ²
AB-13	0.58	0.70	0.31	1.08	0.99	0.70
AB-14	0.63	0.73	0.35	0.76	0.88	0.45
AC-29	0.65	0.72	0.37	0.74	0.94	0.46
BA-1	0.66	0.83	0.43	1.21	0.97	0.94
BA-9	0.65	0.81	0.40	1.04	0.89	0.63
CB-11	0.66	0.78	0.41	0.83	1.04	0.60
CC-23	0.66	0.75	0.39	1.00	0.83	0.49
DA-3	0.62	0.91	0.42	1.05	0.92	0.68
DC-22	0.65	0.89	0.41	1.21	0.91	0.84
EA-7	0.70	0.73	0.41	1.33	1.12	1.06
EB-14	0.69	0.79	0.43	1.10	1.00	0.81
EC-25	0.63	0.88	0.42	1.07	1.01	0.78
EC-27	0.64	0.79	0.40	0.79	0.94	0.50
FB-19	0.63	0.72	0.35	0.69	0.88	0.41
FC-24	0.65	0.79	0.40	1.15	0.89	0.74
FC-25	0.61	0.75	0.38	0.84	0.94	0.56
GA-4	0.66	0.79	0.42	1.34	0.95	0.85
GB-16	0.63	0.76	0.37	0.90	0.91	0.55
HA-2	0.66	0.79	0.41	1.15	0.94	0.85
HA-7	0.60	0.72	0.32	0.70	0.82	0.40
HC-24	0.70	0.79	0.42	1.70	1.43	1.62
IA-1	0.70	0.83	0.46	1.24	1.04	0.89
IA-5	0.69	0.76	0.42	0.79	1.01	0.54

F2 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT
+35 ksi TO 8000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	$N_0=0$			$N_1=4000$		
	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
AA-7	0.69	0.79	0.42	0.94	1.32	0.81
AA-9	0.69	0.81	0.45	a	a	a
AC-24	0.68	0.84	0.49	1.02	1.10	0.85
BA-6	0.68	0.80	0.48	a	a	a
BB-12	0.71	0.87	0.51	a	a	a
BC-30	0.70	0.78	0.42	0.82	0.97	0.58
CB-12	0.66	0.81	0.51	0.91	1.03	0.67
CB-16	0.62	0.78	0.37	0.94	0.94	0.55
DA-5	0.70	0.83	0.48	1.24	0.96	0.95
DB-18	0.66	0.74	0.42	0.86	1.01	0.67
DC-29	0.66	0.79	0.34	0.65	2.19	0.65
EA-5	0.64	0.78	0.45	1.99	1.51	2.35
EC-24	0.68	0.83	0.44	0.95	1.01	0.68
EC-29	0.64	0.74	0.40	0.97	1.06	0.72
FA-6	0.66	0.71	0.41	1.26	1.06	0.96
FB-11	0.88	0.99	0.65	1.66	1.12	1.26
FC-26	0.70	0.81	0.46	1.66	1.51	1.70
GA-6	0.71	0.76	0.47	2.16	1.66	2.28
GC-22	0.70	0.77	0.43	1.58	1.28	1.52
HB-15	0.61	0.72	0.42	a	a	a
HB-16	0.66	0.74	0.42	0.98	1.03	0.70
IB-15	0.69	0.76	0.43	1.12	1.06	0.85
IC-27	0.71	0.83	0.48	1.89	1.32	1.94

a = Specimen failed

F3 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT
+35ksi TO 12,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N ₀ =0			N ₃ =12,000		
	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
AA-5	0.66	0.81	0.41	1.03	1.02	0.77
AC-27	0.61	0.76	0.36	0.72	1.01	0.57
BB-19	0.65	0.75	0.37	0.96	1.08	0.77
BC-21	0.69	0.84	0.43	0.86	1.06	0.74
CA-2	0.66	0.77	0.38	0.70	1.04	0.53
CA-6	0.64	0.81	0.39	a	a	a
CB-14	0.65	0.77	0.39	1.07	1.10	0.81
DA-2	0.64	0.84	0.42	a	a	a
DA-10	0.60	0.74	0.35	0.83	0.97	0.47
DB-15	0.68	0.79	0.42	1.68	1.45	1.64
DB-19	0.66	0.76	0.38	0.78	1.04	0.57
EA-4	0.65	0.79	0.42	a	a	a
FA-1	0.66	0.83	0.46	1.38	1.21	1.20
FB-18	0.66	0.78	0.41	a	a	a
GA-5	0.67	0.82	0.44	1.13	1.04	0.92
GB-18	0.63	0.77	0.38	0.90	0.94	0.64
HA-6	0.70	0.75	0.40	1.21	1.15	0.88
HA-8	0.63	0.76	0.35	1.31	1.16	1.00
HB-19	0.64	0.74	0.38	a	a	a
HC-21	0.70	0.85	0.48	1.97	1.52	1.93
IA-2	0.69	0.82	0.45	1.42	1.23	1.29
IA-6	0.65	0.81	0.39	1.04	1.01	0.69
IA-8	0.64	0.77	0.38	0.88	1.01	0.63

a = Specimen failed

F4 - DAMANGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT
+35ksi TO 20,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N _o = 0			N ₄ = 20,000		
	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
AA-3	0.70	0.76	0.42	0.91	1.07	1.05
AB-17	0.70	0.83	0.53	s	a	a
AC-25	0.65	0.82	0.40	1.09	1.30	0.80
BA-8	0.67	0.81	0.44	a	a	a
BB-14	0.72	0.81	0.47	1.20	1.04	0.89
BC-22	0.72	0.81	0.47	a	a	a
BC-28	0.63	0.73	0.37	a	a	a
CA-4	0.72	0.76	0.44	a	a	a
CA-9	0.68	0.76	0.42	a	a	a
CB-17	0.66	0.83	0.41	0.66	0.97	0.49
DB-14	0.68	0.84	0.43	1.14	1.23	0.92
EB-17	0.70	0.86	0.47	a	a	a
EC-26	0.64	0.81	0.39	a	a	a
FA-2	0.70	0.81	0.46	1.57	1.10	1.16
FB-15	0.64	0.77	0.39	1.77	1.45	1.74
FC-29	0.66	0.72	0.40	1.35	1.19	1.10
GC-23	0.72	0.78	0.48	1.01	1.30	0.97
GC-25	0.71	0.81	0.42	1.63	1.36	1.30
GC-24	0.66	0.79	0.40	1.27	1.06	0.91
HB-12	0.62	0.81	0.38	a	a	a
HC-29	0.65	0.73	0.39	a	a	a
IB-12	0.62	0.71	0.40	0.92	1.12	0.69
IB-14	0.63	0.81	0.38	a	a	a

a = Specimen failed

F5 - DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED AT
+35ksi TO 40,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	N ₀ =0			N ₅ =40,000		
	WIDTH X,in.	LENGTH Y,in.	AREA A,in. ²	WIDTH X,in.	LENGTH Y,in.	AREA A,in. ²
A-26	0.63	0.72	0.36	0.93	1.21	0.71
AA-8	0.61	0.75	0.38	a	a	a
B-15	0.68	0.86	0.46	1.62	2.56	2.86
B-25	0.55	0.69	0.34	1.31	1.17	1.33
B-26	0.62	0.75	0.38	a	a	a
C-19	0.59	0.74	0.36	1.44	1.21	1.42
C-24	0.60	0.77	0.36	1.08	1.26	0.82
C-27	0.65	0.79	0.41	1.50	1.22	1.35
CA-3	0.66	0.85	0.43	a	a	a
D-13	0.64	0.78	0.40	a	a	a
D-26	0.59	0.80	0.55	a	a	a
E-9	0.58	0.68	0.33	1.30	1.46	1.23
E-15	0.65	0.83	0.61	a	a	a
E-30	0.59	0.73	0.34	2.17	1.45	2.16
F-7	0.61	0.70	0.36	a	a	a
F-27	0.61	0.72	0.36	0.93	1.21	0.86
G-1	0.63	0.80	0.40	a	a	a
G-3	0.61	0.75	0.39	a	a	a
G-9	0.59	0.68	0.36	1.32	1.35	1.53
G-15	0.65	0.83	0.41	a	a	a
H-3	0.61	0.75	0.39	a	a	a
H-30	0.62	0.72	0.55	1.97	1.50	2.50
I-16	0.63	0.76	0.38	1.14	1.28	0.93

a = Specimen failed

F6 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT
+22ksi TO 1000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID.	$N_0 = 0$			$N_1 = 1000$		
	WIDTH X, in.	LENGTH Y, in	AREA A, in ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in ²
JB-13	0.83	0.80	0.54	0.88	0.80	0.53
JB-16	0.71	0.70	0.42	0.74	0.72	0.44
JG-22	0.92	0.86	0.60	1.01	0.88	0.70
KA-9	0.81	0.84	0.58	1.06	0.88	0.69
KB-18	0.87	0.77	0.55	0.81	0.81	0.53
KE-27	0.75	0.81	0.51	0.81	0.81	0.54
LA-3	0.83	0.79	0.56	1.17	0.81	0.75
LA-9	0.87	0.86	0.59	0.97	0.87	0.67
MA-8	0.82	0.83	0.56	1.16	0.81	0.73
MC-23	0.80	0.88	0.60	1.08	0.86	0.61
MC-28	0.73	0.76	0.47	0.99	0.81	0.60
NA-4	0.86	0.83	0.57	1.23	0.87	0.84
NC-28	0.84	0.83	0.60	1.21	0.83	0.75
NC-30	0.77	0.77	0.54	1.12	0.80	0.70
PA-3	0.80	0.70	0.47	0.79	0.76	0.47
PA-9	0.79	0.78	0.54	1.11	0.79	0.67
QA-4	0.83	0.86	0.60	1.13	0.90	0.76
QA-6	0.83	0.90	0.61	1.13	0.90	0.78
QB-17	0.83	0.81	0.56	0.76	0.80	0.53
RA-2	0.86	0.88	0.65	1.44	0.89	0.89
RC-29	0.86	0.90	0.69	1.03	0.91	0.74
SA-7	0.80	0.80	0.55	0.97	0.83	0.65
SB-19	0.88	0.81	0.57	0.97	0.86	0.66

**F7 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT
+22ksi TO 5,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II**

SPEC ID	$N_0 = 0$			$N_2 = 5000$		
	WIDTH X, in	LENGTH Y, in	AREA A, in^2	WIDTH X, in	LENGTH Y, in	AREA A, in^2
JA-4	0.97	0.89	0.74	1.19	0.87	0.76
JA-5	0.88	0.81	0.58	1.74	0.86	0.94
KB-16	0.92	0.92	0.66	1.52	0.92	0.92
KC-24	0.82	0.88	0.57	1.01	0.88	0.67
KC-28	0.81	0.86	0.58	0.90	0.81	0.54
LA-2	0.86	0.90	0.61	1.38	0.86	0.78
LB-16	0.84	0.83	0.58	1.37	0.85	0.87
MA-6	0.84	0.81	0.56	1.99	0.88	1.11
MB-16	0.89	0.86	0.45	1.47	0.85	0.78
MC-22	0.74	0.74	0.49	1.79	0.84	0.98
NA-2	0.81	0.83	0.56	1.40	0.85	0.81
NC-22	0.79	0.88	0.57	1.77	0.83	1.02
NC-26	0.77	0.83	0.51	1.25	0.82	0.70
PB-15	0.72	0.74	0.44	0.82	0.74	0.69
PC-25	0.85	0.83	0.57	1.61	0.85	0.86
QA-1	0.87	0.90	0.58	1.34	0.88	0.52
QA-9	0.76	0.81	0.52	1.88	0.77	0.85
QC-28	0.80	0.89	0.57	1.41	0.88	0.84
RB-19	0.83	0.88	0.59	1.11	0.90	0.69
RB-20	0.47	0.80	0.49	1.12	0.77	0.54
RC-27	0.87	0.89	0.61	1.87	0.87	0.99
SB-13	0.91	1.00	0.72	1.20	0.94	0.81
SC-22	0.83	0.92	0.58	1.72	0.92	0.98

F8 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT
+22ksi TO 10,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	$N_0 = 0$			$N_3 = 10,000$		
	WIDTH X, in	LENGTH Y, in	AREA A, in ²	WIDTH X, in	LENGTH Y, in	AREA A, in ²
JC-27	0.87	0.92	0.70	1.49	0.89	0.84
JC-28	0.87	0.87	0.58	1.50	0.98	1.01
KA-2	0.83	0.87	0.57	2.04	0.89	2.30
KA-7	0.84	0.87	0.59	1.37	0.84	0.85
KC-22	0.81	0.80	0.52	1.39	0.84	0.81
LA-7	0.83	0.83	0.55	1.49	0.81	0.80
LC-23	0.83	0.86	0.58	1.57	0.88	0.96
LC-27	0.79	0.85	0.51	1.50	0.86	0.98
MC-25	0.78	0.77	0.51	1.11	0.93	0.71
MC-29	0.81	0.77	0.53	1.03	0.88	0.66
NB-13	0.81	0.79	0.50	1.14	0.83	0.67
NB-16	0.81	0.89	0.57	2.67	0.89	1.42
PA-1	0.77	0.67	0.42	1.41	0.83	0.80
PA-4	0.83	0.74	0.46	1.46	0.85	0.79
PC-21	0.72	0.69	0.42	0.72	0.68	0.39
PC-27	0.76	0.74	0.49	0.88	0.76	0.46
QB-12	0.79	0.83	0.52	1.79	0.88	1.05
QC-23	0.83	0.89	0.59	1.77	0.87	0.81
RB-17	0.79	0.80	0.50	1.64	0.83	0.92
RC-23	0.95	1.00	0.73	1.86	0.94	1.06
SA-3	0.81	0.86	0.54	1.61	0.97	0.95
SA-5	0.77	0.76	0.47	1.11	0.81	0.63
SB-11	0.90	0.89	0.62	1.88	0.87	1.07

F9 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT
+22ksi TO 20,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	$N_0 = 0$			$N_4 = 20,000$		
	WIDTH	LENGTH	AREA	WIDTH	LENGTH	AREA
	X, in	Y, in	A, in ²	X, in	Y, in	A, in ²
JB-11	0.81	0.83	0.54	1.30	0.98	0.92
JB-14	0.76	0.78	0.48	1.50	0.84	0.88
JB-15	0.80	0.83	0.52	1.00	0.89	0.64
KB-12	0.72	0.80	0.51	1.38	0.90	0.95
LA-4	0.81	0.81	0.53	2.00	0.96	1.21
LA-5	0.80	0.81	0.53	2.18	0.94	1.10
LC-31	0.70	0.77	0.42	1.41	0.86	0.84
MB-11	0.79	0.83	0.50	2.62	0.88	1.37
MB-13	0.83	0.84	0.53	2.02	0.94	1.09
MB-18	0.84	0.84	0.56	1.57	0.88	0.93
NA-6	0.87	0.92	0.62	1.41	0.96	0.97
NB-17	0.93	0.94	0.66	1.30	0.93	0.90
NB-19	0.79	0.85	0.54	1.12	1.01	0.74
PB-17	0.74	0.72	0.42	2.06	0.91	0.96
QB-13	0.86	0.92	0.59	2.01	0.95	1.20
QC-22	0.93	0.90	0.64	1.86	1.00	1.28
QC-30	0.80	0.73	0.49	1.68	0.82	0.84
RA-7	0.85	0.90	0.60	1.59	0.94	1.00
RC-22	0.96	0.97	0.74	1.42	0.98	1.02
RC-24	0.83	0.88	0.58	2.44	0.93	1.37
SA-9	0.90	0.85	0.59	a	a	a
SC-23	0.82	0.86	0.56	2.38	0.89	1.44
SC-27	0.81	0.86	0.60	2.19	1.05	1.28

F10 - DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED AT
+22ksi TO 28,000 CYCLES FOR RESIDUAL STRENGTH DETERMINATION - TASK II

SPEC ID	N = 0			N = 28,000		
	WIDTH X,in	LENGTH Y,in	AREA A,in ²	WIDTH X,in	LENGTH Y,in	AREA A,in ²
JB-18	0.92	0.85	0.64	2.89	1.10	1.94
JC-23	0.86	0.88	0.56	2.48	1.05	1.52
JC-30	0.87	0.87	0.62	1.64	0.94	1.05
KA-5	0.84	0.86	0.57	2.39	0.94	1.33
KB-14	0.82	0.83	0.54	2.47	0.93	1.40
KB-17	0.84	0.82	0.54	2.57	1.04	1.63
LB-19	0.84	0.81	0.58	1.74	0.95	2.18
LC-26	0.85	0.80	0.53	2.54	1.01	1.49
MA-4	0.85	0.81	0.56	2.44	2.57	2.94
MB-15	0.69	0.67	0.36	0.88	0.75	0.42
NB-14	0.79	0.75	0.47	1.52	0.84	0.78
NB-18	0.83	0.86	0.56	2.52	1.00	1.46
PA-7	0.84	0.89	0.61	2.55	0.95	1.54
PB-12	0.85	0.83	0.56	2.59	1.03	1.57
PB-13	0.86	0.89	0.68	2.63	1.01	1.54
QC-24	0.81	0.80	0.51	1.16	0.88	0.45
QC-31	0.76	0.83	0.49	2.04	0.83	0.99
RA-5	0.91	0.91	0.62	2.61	0.94	1.49
RC-25	0.90	0.97	0.68	2.73	1.00	1.77
RC-31	0.76	0.81	0.48	2.54	1.19	1.60
SB-17	0.87	0.87	0.57	2.17	0.94	1.23
SB-18	0.81	0.90	0.58	2.21	0.98	1.34
SC-31	0.81	0.87	0.56	1.72	0.96	1.43

TABLE F11
DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED
UNDER CONDITION A, 4-BAR SUPPORT FOR RESIDUAL STRENGTH DETERMINATION
TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_0 = 0$			$N_1 = 4,000$			
AB-14	0.70	0.88	0.49	0.93	1.26	0.88
AC-26	0.66	0.75	0.43	1.06	1.02	0.84
BA-7	0.61	0.68	0.35	0.57	0.82	0.39
BC-27	0.68	0.89	0.50	1.22	1.05	0.89
CA-2	0.67	0.81	0.47	1.90	1.23	1.52
CA-9	0.68	0.84	0.46	0.77	1.07	0.65
$N_0 = 0$			$N_2 = 8000$			
AB-16	0.59	0.70	0.34	0.86	0.90	0.54
AB-19	0.63	0.79	0.43	1.18	1.10	1.01
BA-4	0.62	0.73	0.36	1.10	1.15	1.00
CA-7	0.67	0.83	0.48	0.99	1.05	0.78
CA-10	0.70	0.85	5.00	1.17 1.26	1.08	0.96 1.09
CC-23	0.71	0.88	0.50	-	-	-
$N_0 = 0$			$N_3 = 12000$			
AA-7	0.68	0.77	0.46	1.24	1.26	1.28
AC-31	0.66	0.80	0.44	1.25	1.50	1.23
BB-11	0.70	0.84	0.49	2.07	1.38	2.22
BB-13	0.59	0.68	0.31	0.59	0.92	0.40
CC-21	0.68	0.83	0.49	1.83	1.48	1.91
CC-26	0.68	0.81	0.43	1.56	1.17	1.32

TABLE F12
DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED
UNDER CONDITION B, R = -0.3 FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_0 = 0$			$N_1 = 4,000$			
AB-12	0.70	0.84	0.50	0.70	1.30	0.68
AC-25	0.68	0.83	0.46	0.75	1.24	0.71
BC-22	0.69	0.86	0.46	0.70	1.19	0.63
BC-25	0.64	0.73	0.40	0.64	1.25	0.67
CB-16	0.57	0.67	0.31	0.57	0.99	0.48
CC-28	0.70	0.85	0.48	0.69	1.26	0.65
$N_0 = 0$			$N_2 = 40,000$			
AA-10	0.69	0.86	0.45	0.70	1.81	0.88
AB-20	0.59	0.71	0.36	0.64	1.59	0.73
BB-15	0.67	0.86	0.46	0.72	1.65	0.83
BB-19	0.68	0.80	0.45	0.72	1.66	0.86
CA-3	0.68	0.89	0.51	0.72	1.88	1.02
CB-13	0.68	0.87	0.50	0.72	1.73	0.91
$N_0 = 0$			$N_3 = 250K$			
AB-15	0.70	0.86	0.48	0.70	2.13	1.08
AC-24	0.67	0.88	0.51	0.72	2.14	1.10
BA-10	0.68	0.85	0.50	0.70	2.21	1.07
				0.68	2.19	1.07
BC-31	0.68	0.89	0.49	0.72	2.00	0.93
CB-11	0.69	0.81	0.47	0.68	1.84	0.94
CB-15	0.71	0.86	0.50	0.68	1.99	0.98

TABLE F13
DAMAGE MEASUREMENTS FOR 24-PLY SPECIMENS FATIGUE CYCLED
UNDER CONDITION C, 180°F FOR RESIDUAL STRENGTH DETERMINATION - TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_0 = 0$			$N_1 = 50$			
AA-3	0.68	0.87	0.47	0.88	0.91	0.58
AC-23	0.70	0.81	0.48	1.05	0.81	0.63
BB-20	0.66	0.84	0.45	0.68	0.88	0.47
BC-28	0.69	0.89	0.47	0.75	0.90	0.50
CB-14	0.69	0.80	0.48	0.72	0.91	0.54
CB-19	0.57	0.69	0.31	0.62	0.71	0.36
$N_0 = 0$			$N_2 = 300$			
AA-5	0.63	0.84	0.42	0.95	0.86	0.64
AB-13	0.68	0.90	0.49	0.70	0.93	0.56
BB-14	0.69	0.90	0.48	0.90	0.90	0.94
BB-17	0.66	0.79	0.39	0.68	0.88	0.48
CA-5	0.70	0.81	0.46	1.27	0.93	0.92
CC-30	0.67	0.86	0.52	1.08	0.95	0.78
$N_0 = 0$			$N_3 = 1000$			
AA-6	0.63	0.75	0.39	1.49	1.04	1.14
AC-30	0.56	0.68	0.31	0.81	0.79	0.50
BA-9	0.67	0.88	0.47	1.01	0.83	0.74
BB-16	0.62	0.79	0.32	0.66	0.79	0.41
CB-18	0.60	0.77	0.36	0.80	0.87	0.48
CB-20	0.61	0.77	0.41	0.87	0.77	0.50

TABLE F14
DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED
UNDER CONDITION A, 4-BAR SUPPORT FOR RESIDUAL STRENGTH DETERMINATION
TASK III

SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_0 = 0$			$N_1 = 1,000$			
DB-13	0.77	0.79	0.46	0.97	0.86	0.58
DC-26	0.83	0.87	0.59	1.22	0.86	0.69
EA-1	0.75	0.83	0.48	0.91	0.85	0.58
EB-22	0.80	0.77	0.47	1.17	0.84	0.66
FC-23	0.75	0.75	0.44	1.08	0.74	0.58
FC-28	0.82	0.74	0.46	0.92	0.79	0.60
$N_0 = 0$			$N_2 = 10,000$			
DB-18	0.68	0.58	0.31	0.99	0.53	0.40
DC-23	0.77	0.81	0.49	2.87	1.08	1.36
EA-7	0.80	0.75	0.52	2.28	0.87	1.10
EB-17	0.82	0.82	0.52	1.52	0.94	0.89
FA-10	0.77	0.78	0.51	1.68	0.90	0.98
FB-14	0.83	0.88	0.58	1.36	0.92	0.98
$N_0 = 0$			$N_3 = 20,000$			
DA-3	0.81	0.82	0.51	1.02	0.91	0.67
DB-11	0.75	0.74	0.44	1.59	0.96	1.08
EB-20	0.79	0.73	0.48	1.39	0.97	1.00
EC-23	0.73	0.75	0.41	1.03	0.83	0.63
FA-1	0.78	0.74	0.47	1.69	0.97	1.10
FA-2	0.77	0.72	0.47	2.59	0.99	1.48

TABLE F15
DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED UNDER
CONDITION B, R = -0.3 FOR RESIDUAL STRENGTH DETERMINATION - TASK III

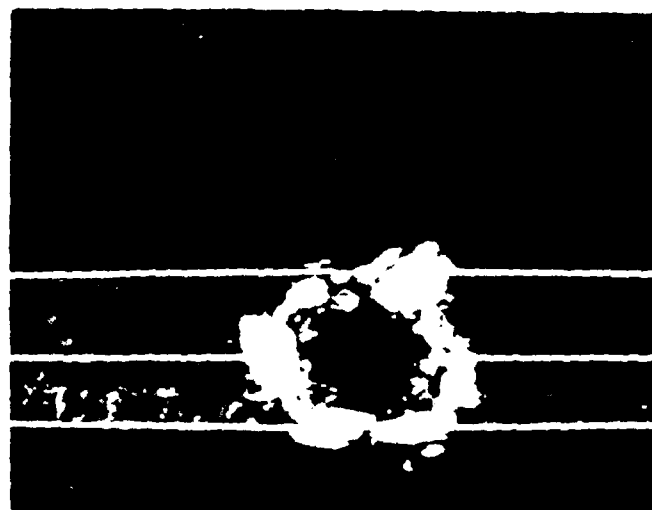
SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_0 = 0$			$N_1 = 20,000$			
EA-6	0.84	0.90	0.60	0.92	0.93	0.63
EC-24	0.68	0.59	0.34	0.70	0.57	0.33
DA-5	0.82	0.95	0.66	0.85	1.03	0.73
DB-19	0.73	0.78	0.44	0.76	0.83	0.47
FA-9	0.84	0.85	0.54	0.83	0.81	0.58
FC-27	0.72	0.72	0.43	0.85	0.78	0.50
$N_0 = 0$			$N_2 = 250K$			
DA-8	0.79	0.77	0.47	1.06	1.10	0.94
DC-30	0.83	0.85	0.58	0.90	1.23	0.84
EA-9	0.79	0.78	0.49	0.88	1.06	0.66
EB-21	0.72	0.74	0.44	0.80	0.91	0.52
FA-7	0.77	0.83	0.50	0.85	0.99	0.64
FC-29	0.80	0.84	0.54	0.95	1.08	0.80
$N_0 = 0$			$N_3 = 10^6$			
DB-14	0.81	0.79	0.52	0.97	1.14	0.90
DB-15	0.77	0.79	0.48	1.10	1.94	1.14
EB-16	0.81	0.88	0.56	0.95	1.22	0.92
EC-31	0.75	0.71	0.44	1.02	1.16	0.98
FB-13	0.77	0.78	0.49	0.84	1.32	1.00
FB-20	0.79	0.84	0.56	0.99	2.53	1.50

TABLE F16
DAMAGE MEASUREMENTS FOR 32-PLY SPECIMENS FATIGUE CYCLED UNDER
CONDITION C, 180°F FOR RESIDUAL STRENGTH DETERMINATION - TASK III

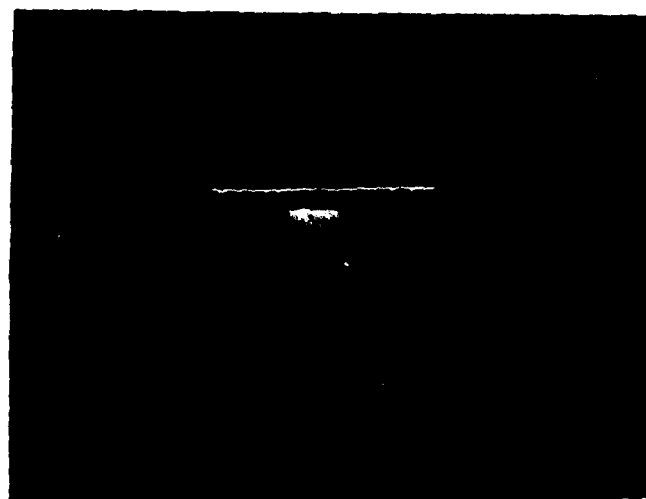
SPEC. ID.	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²	WIDTH X, in.	LENGTH Y, in.	AREA A, in. ²
$N_o = 0$			$N_1 = 1,000$			
DB-12	0.83	0.83	0.54	1.53	0.90	0.93
DE-22	0.77	0.81	0.44	0.91	0.91	0.61
EB-12	0.80	0.78	0.50	1.05	0.88	0.65
EB-19	9.72	0.77	0.44	0.99	0.83	0.65
FB-15	0.73	0.74	0.44	0.94	0.82	0.58
FC-21	0.71	0.77	0.40	0.85	0.72	0.47
$N_o = 0$			$N_2 = 4000$			
DA-1	0.74	0.70	0.44	1.23	0.87	0.86
DB-20	0.77	0.77	0.44	1.40	1.01	0.97
EC-28	0.74	0.85	0.50	1.08	0.86	0.73
EC-29	0.80	0.83	0.54	1.42	0.98	0.92
FA-5	0.83	0.84	0.52	0.95	0.95	0.68
FA-6	0.72	0.77	0.46	0.98	0.76	0.51
$N_o = 0$			$N_3 = 8000$			
DA-10	0.83	0.84	0.57	3.38	1.06	2.29
DB-16	0.83	0.87	0.56	1.26	1.12	1.12
EA-5	0.88	0.84	0.58	1.61	1.04	1.07
EC-27	0.86	0.86	0.59	3.45	1.12	2.47
FB-11	0.83	0.88	0.58	1.12	1.06	0.84

APPENDIX G

Damage as Determined by
Metallographic Sectioning

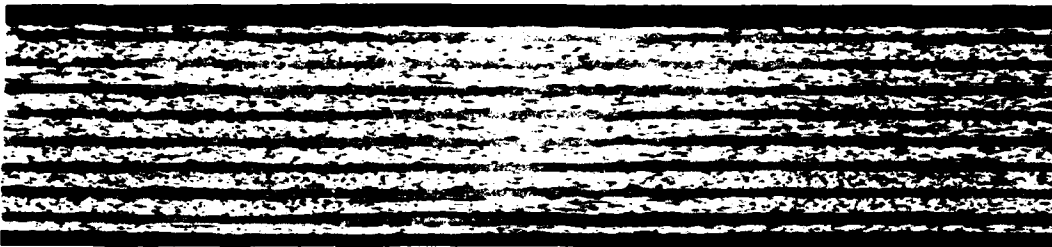


C-SCAN



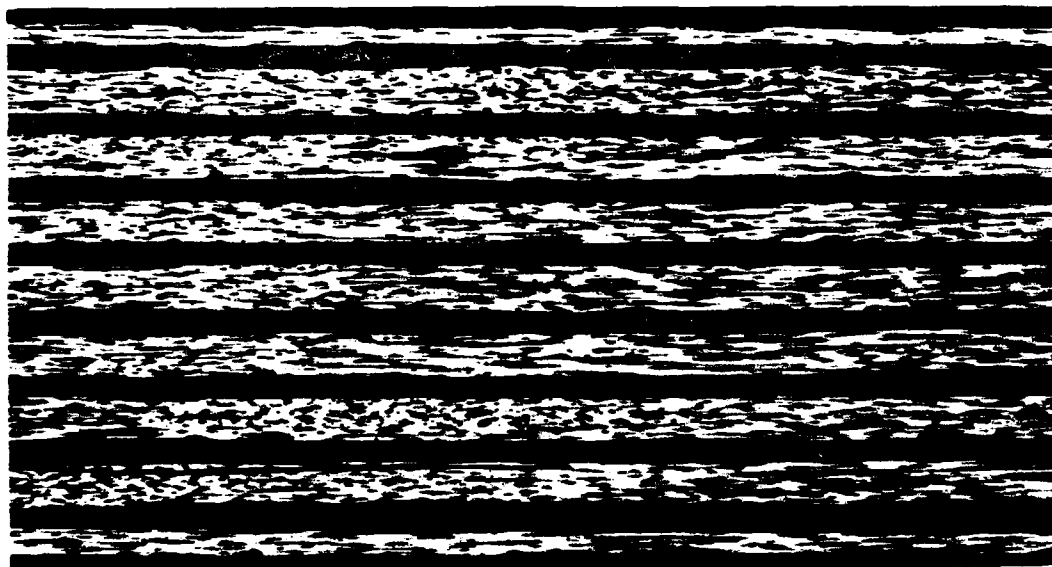
CUMULATIVE B-SCAN

24-PLY SPEC: CB-11 $N_1 = 4,000$ CYCLES



C11-1-1

10X



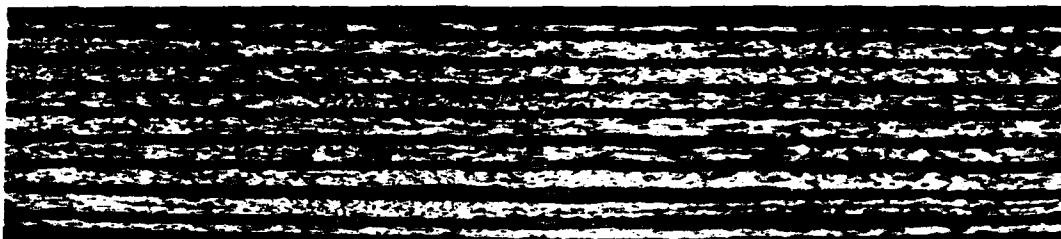
C11-1-2

25X

LOCATION: 1.12 IN. DAMAGE LENGTH: 0.628

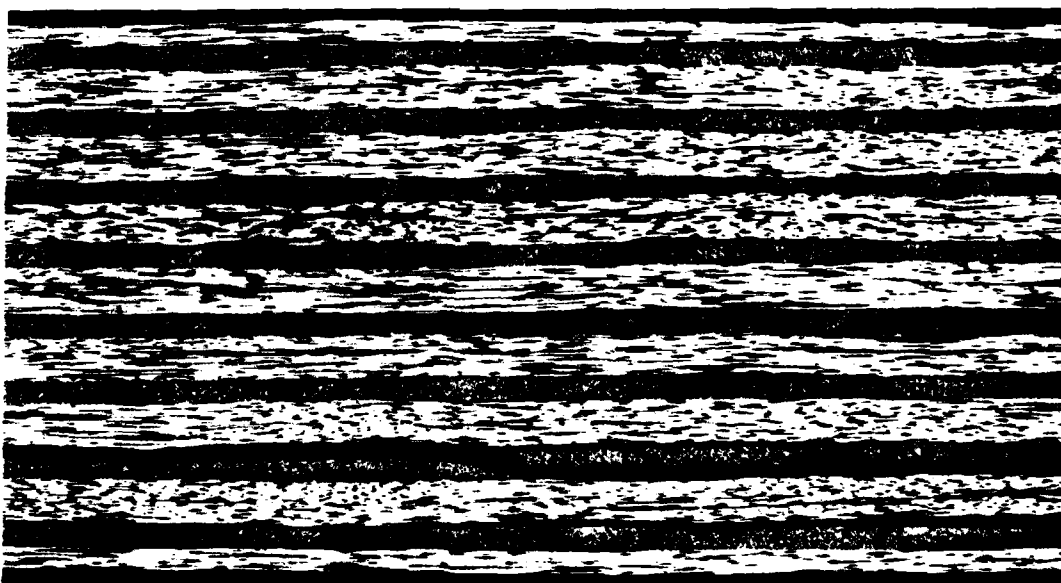


B-SCAN AT 1.15 IN.



C11-2-1

10X



C11-2-2

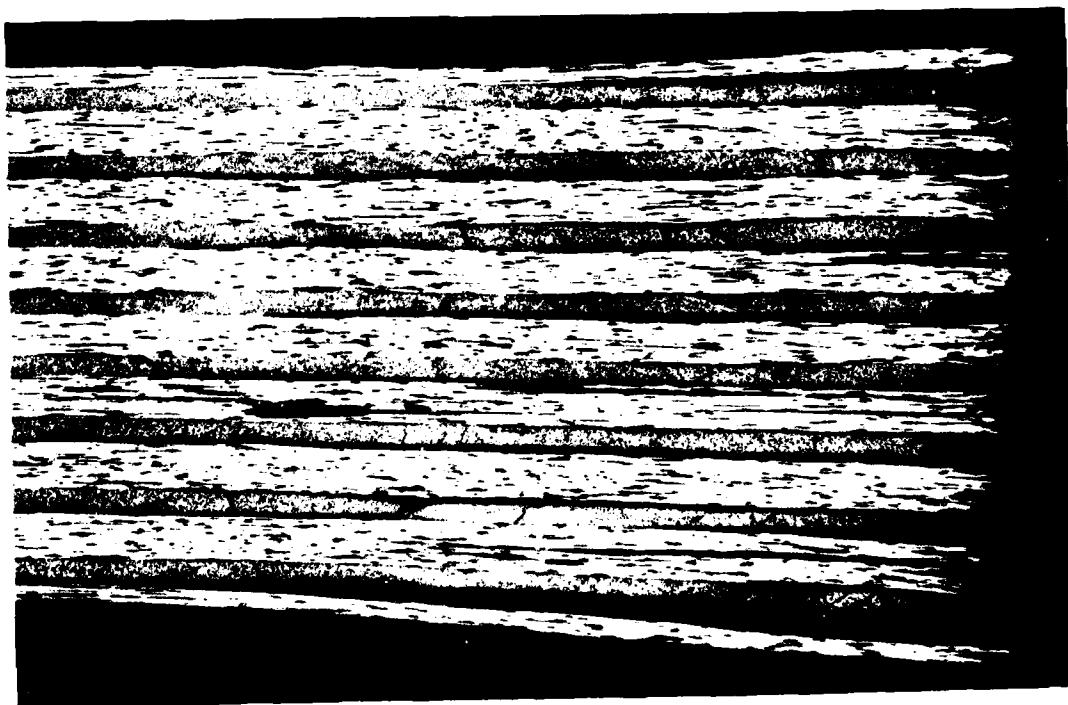
25X

LOCATION: 1.22 IN. DAMAGE LENGTH: 0.704



C11-3-1A

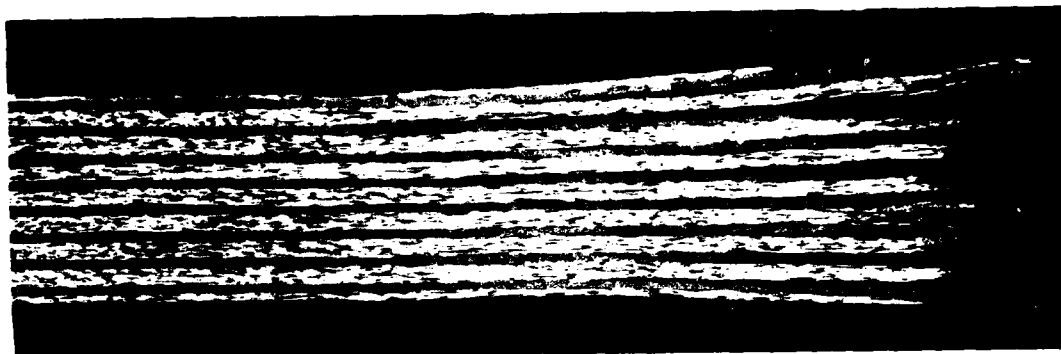
10X



C11-3-2A

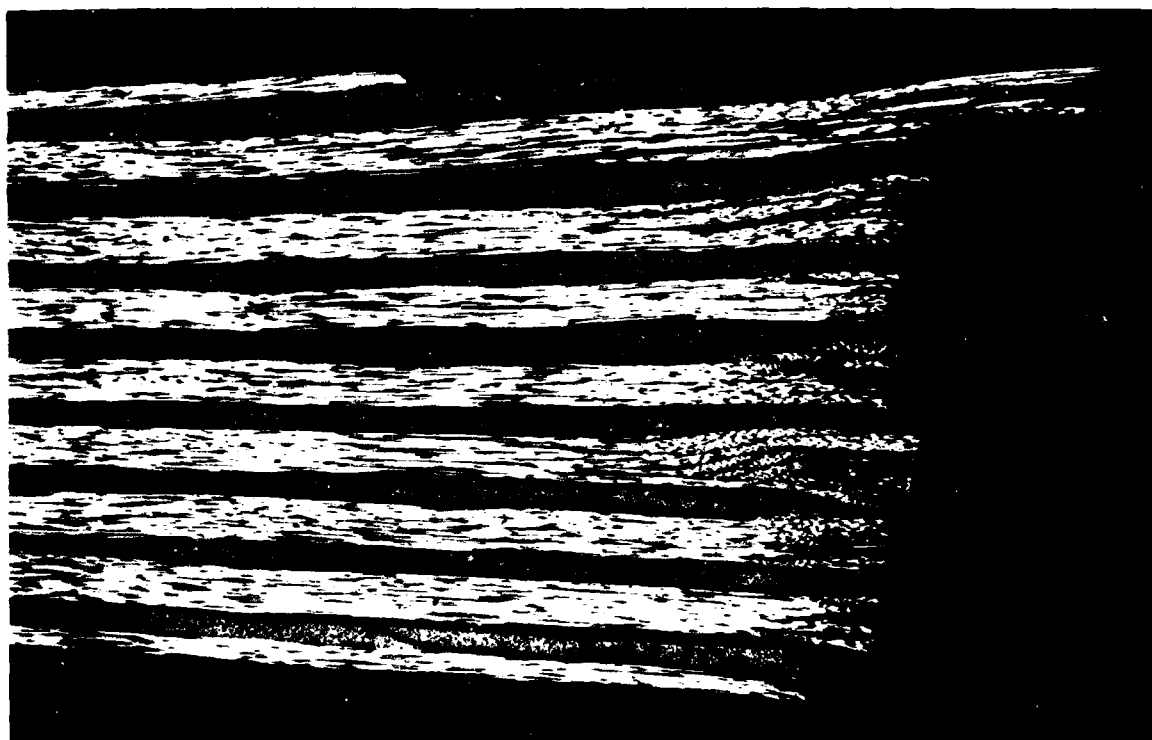
25X

LOCATION: 1.32 IN. DAMAGE LENGTH: 0.757



C11-3-1B

10X



C11-3-2B

25X

LOCATION: 1.32 IN. DAMAGE LENGTH: 0.757

AD-A115 105

LOCKHEED-CALIFORNIA CO BURBANK

F/S 11/4

ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)

JUL 81 K M LAURAITIS, J T RYDER, D E PETTIT

F33615-77-C-3004

UNCLASSIFIED

LA-88369-19

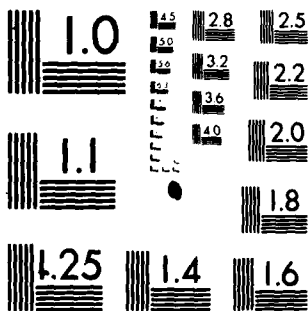
APWAL-TR-79-3095-VOL-3

ML

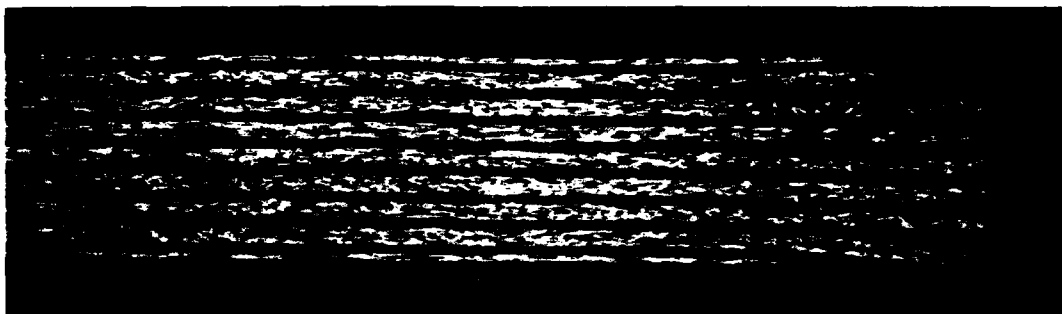
3-5
AD-A115 105



115185

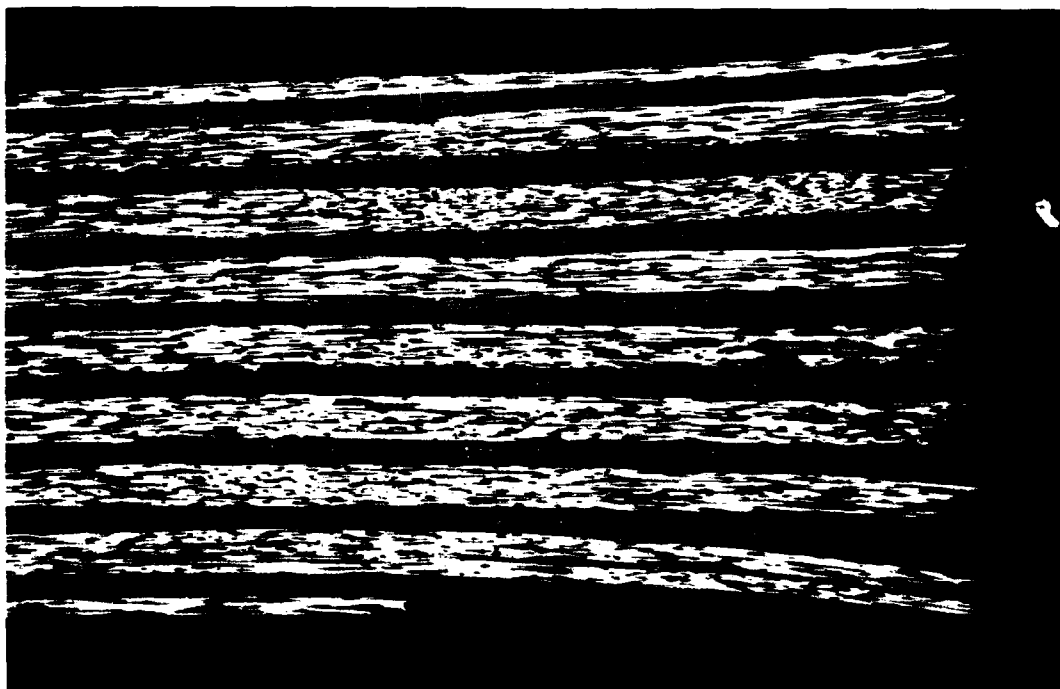


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A



C11-4-1A

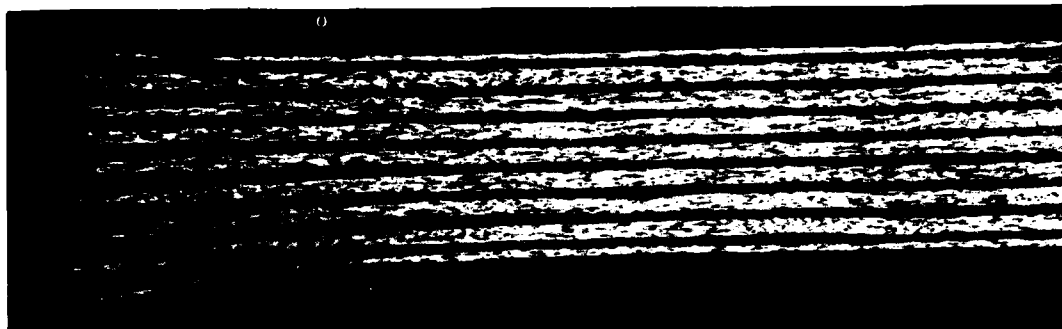
10X



C11-4-2A

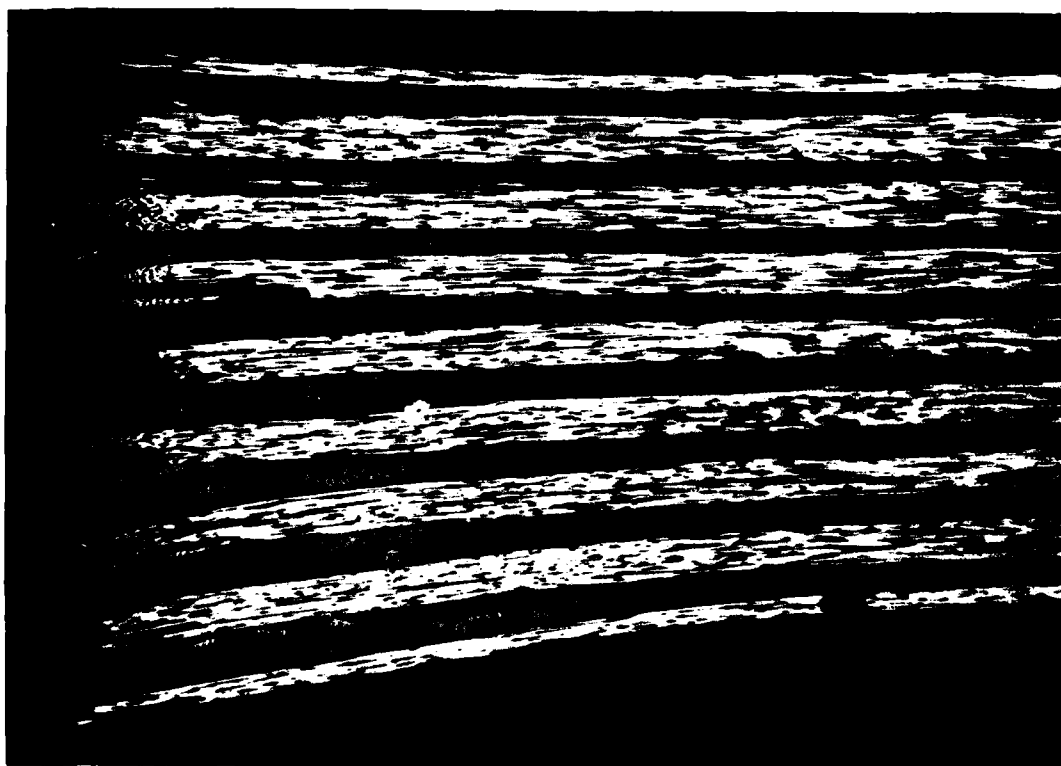
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LOCATION: 1.42 IN. DAMAGE LENGTH: 0.865



C11-4-1B

10X



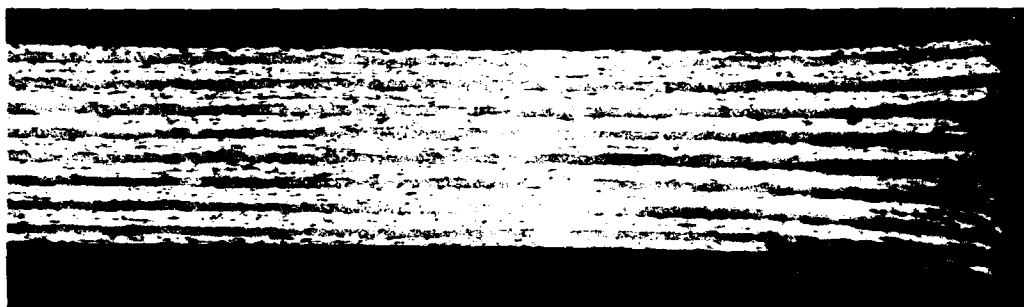
C11-4-2B

25X

LOCATION: 1.42 IN. DAMAGE LENGTH: 0.865

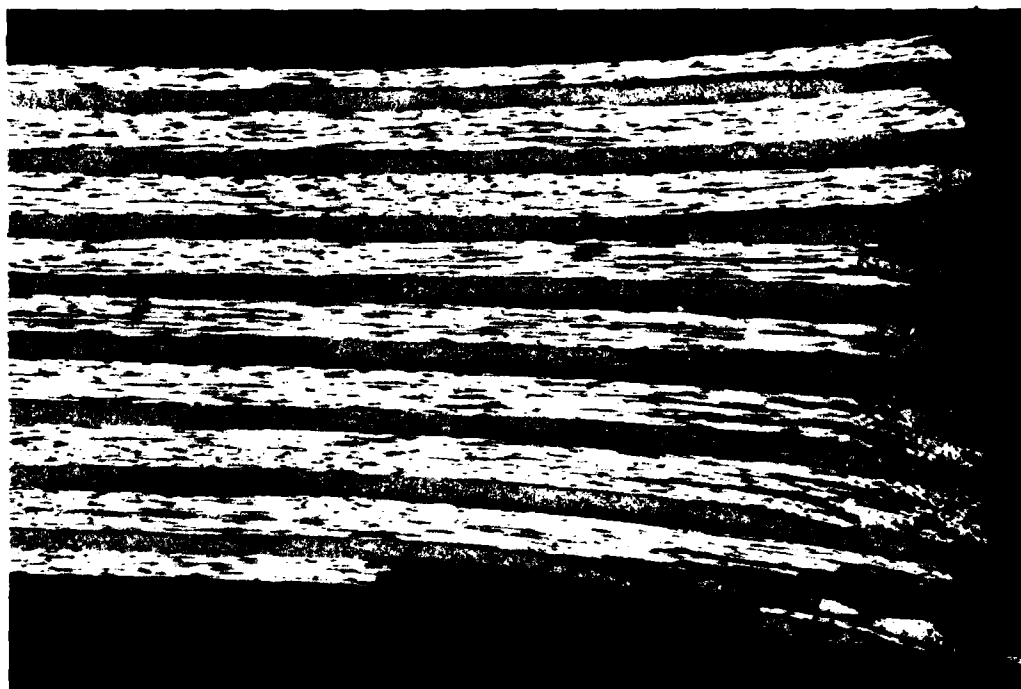
G8

LOCATION: 1.52 in. DAMAGE LENGTH: 0.903



C11-5-1A

10X

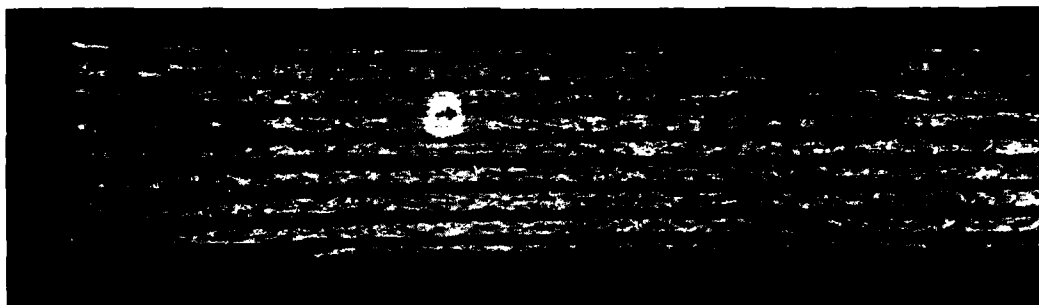


C11-5-2A

25X

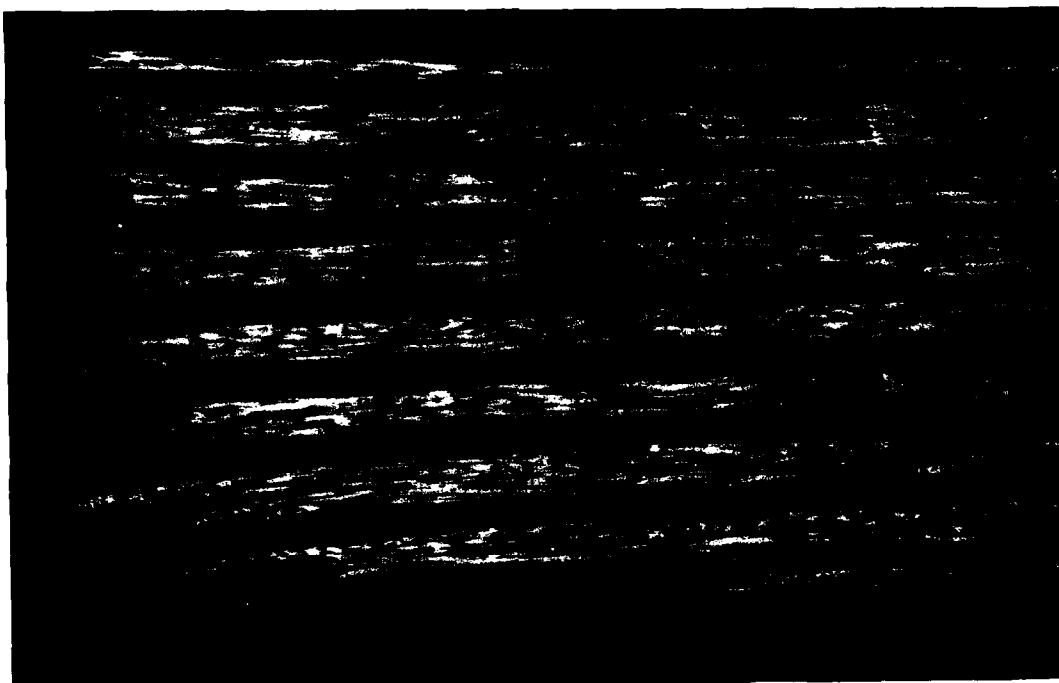


B-SCAN AT CENTER



C11-5-1B

10X



C11-5-2B

25X

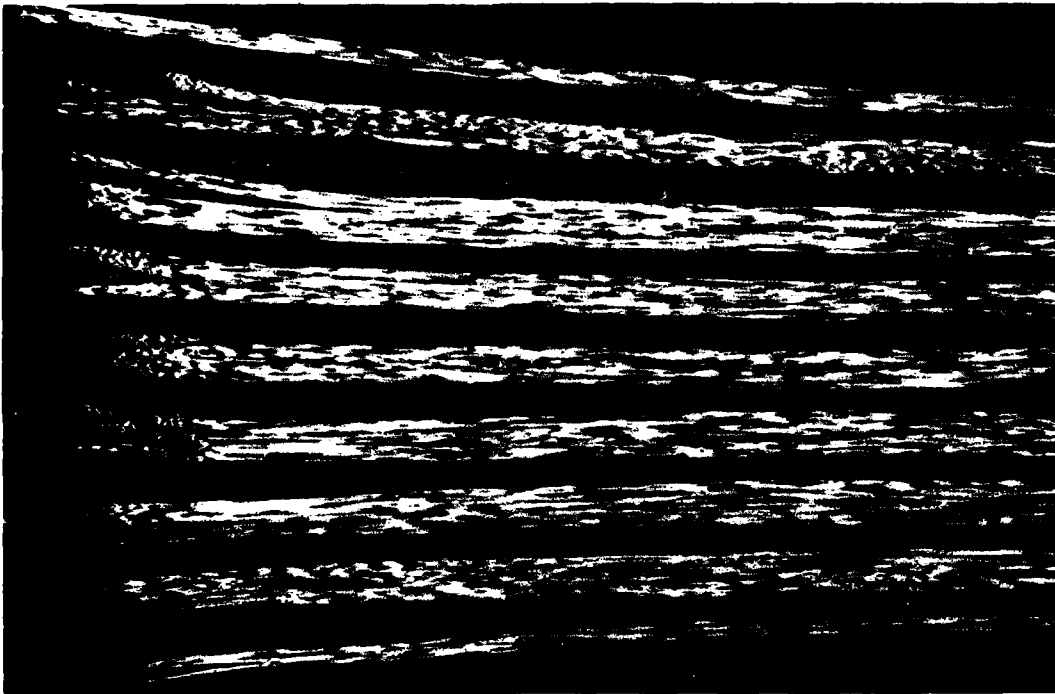
LOCATION: 1.52 IN. DAMAGE LENGTH: 0.903

G10



C11-6-1A

10X



C11-6-2A

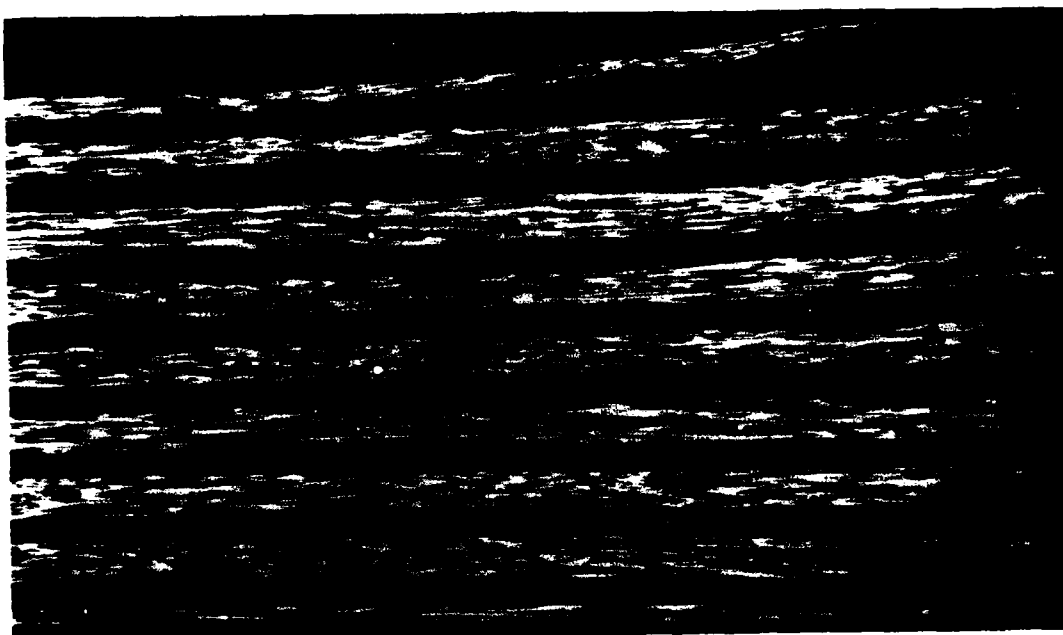
25X

LOCATION: 1.62 IN. DAMAGE LENGTH: 0.867



C11-6-1B

10X



C11-6-2B

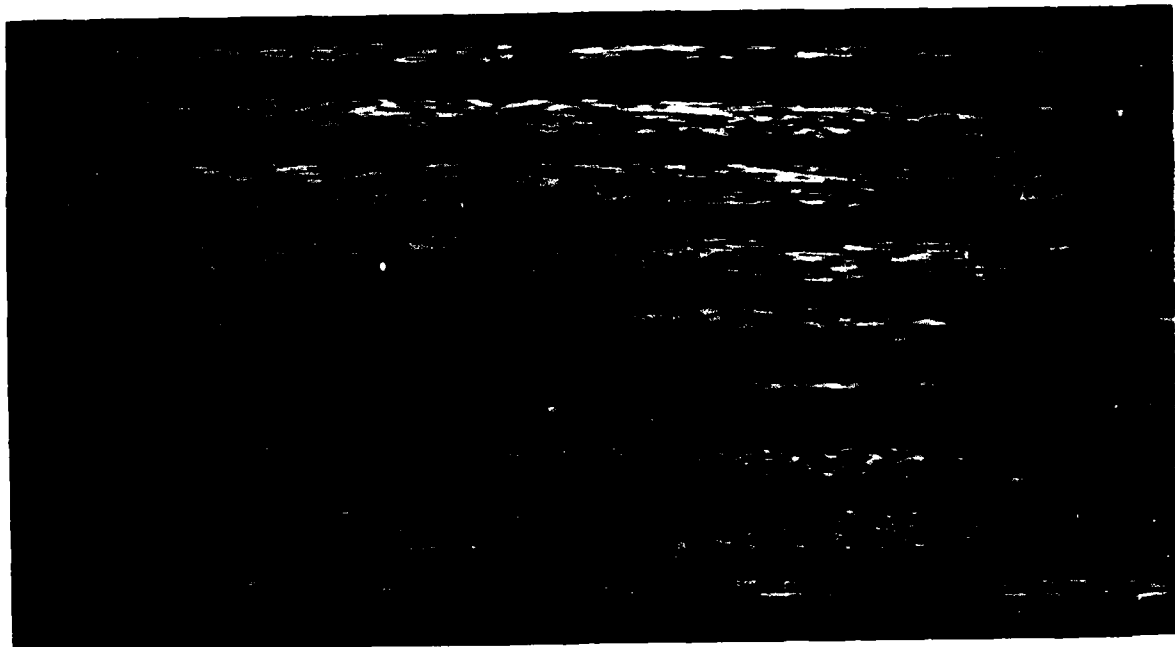
25X

LOCATION: 1.62 in. DAMAGE LENGTH: 0.867



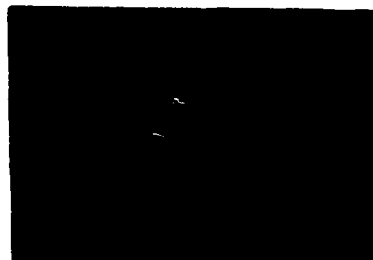
C11-7-1

10X



C-1-7-2

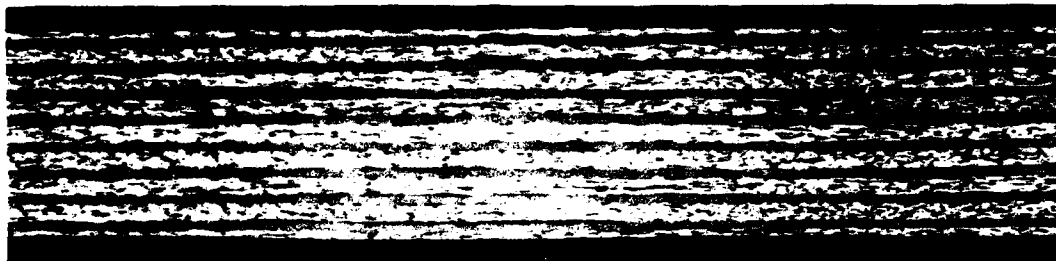
25X



B-SCAN AT 1.78 IN.

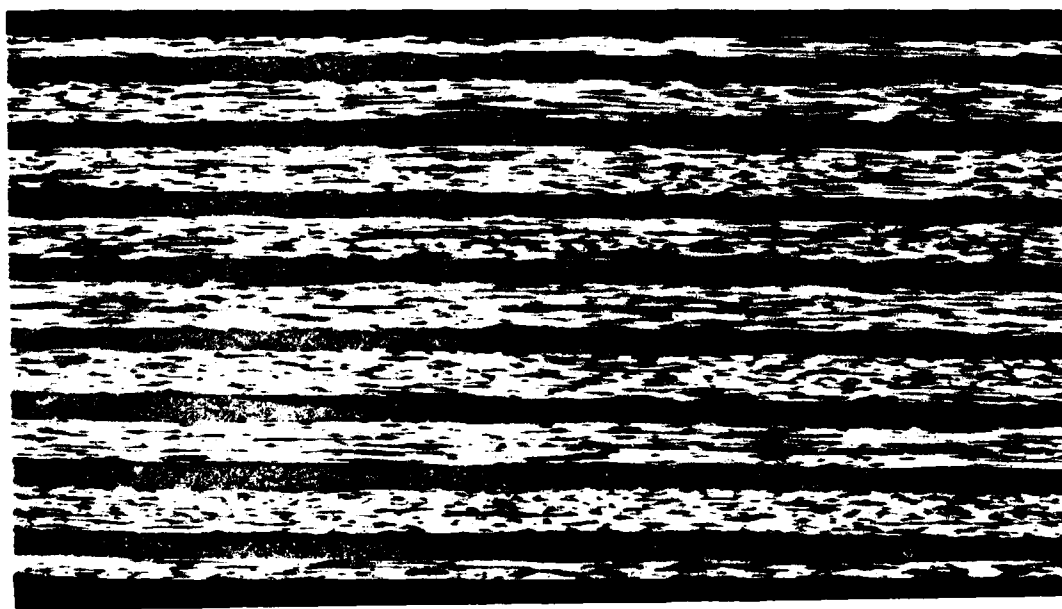
LOCATION: 1.72 IN. DAMAGE LENGTH: 0.653

G13



C11-8-1

10X

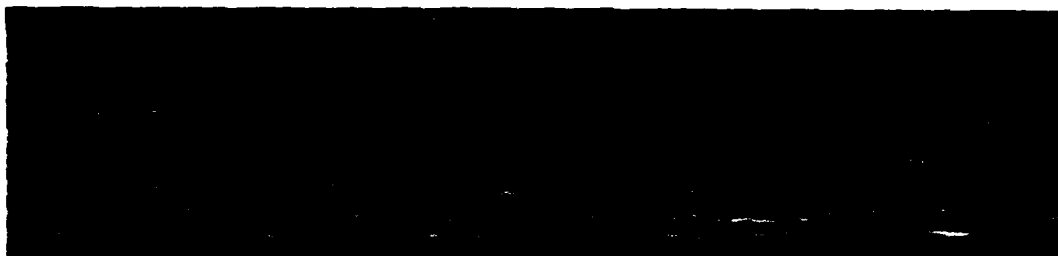


C11-8-2

25X

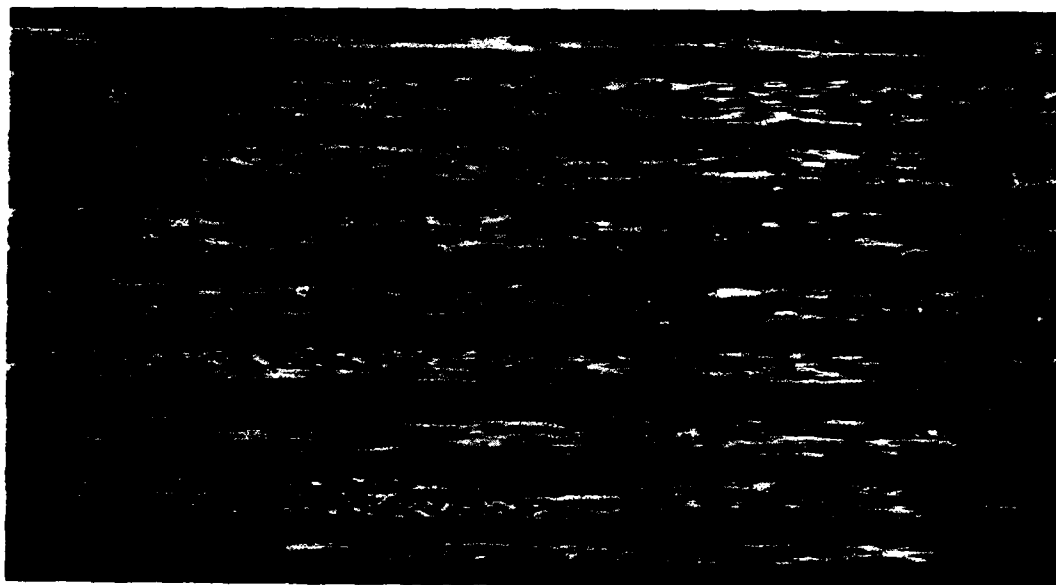
LOCATION: 1.82 IN. DAMAGE LENGTH: 0.290

G14



C11-9-1

10X



C11-9-2

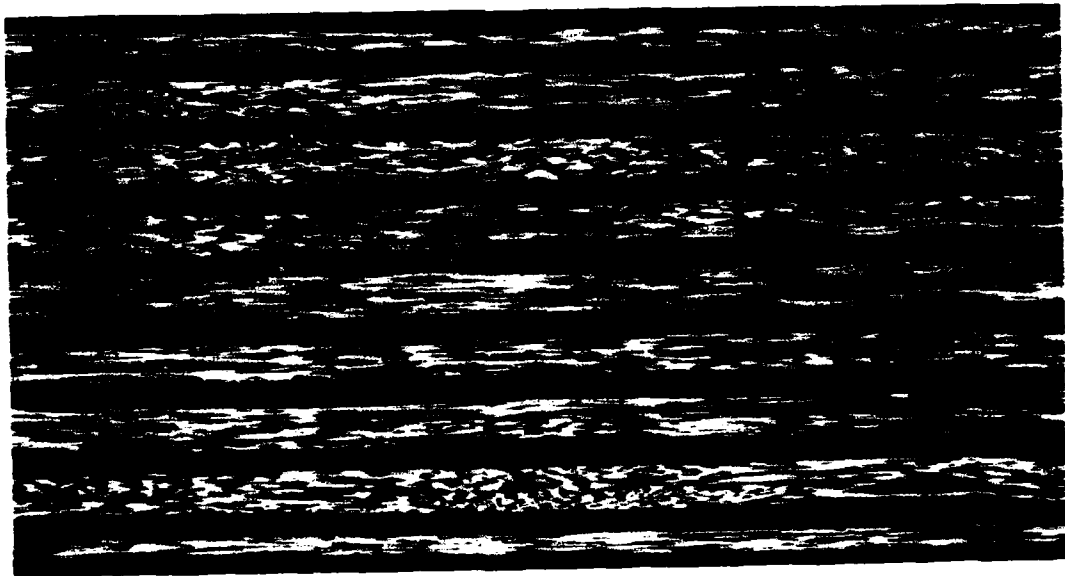
25X

LOCATION: 1.92 IN. DAMAGE LENGTH: NO DAMAGE



C11-10-1

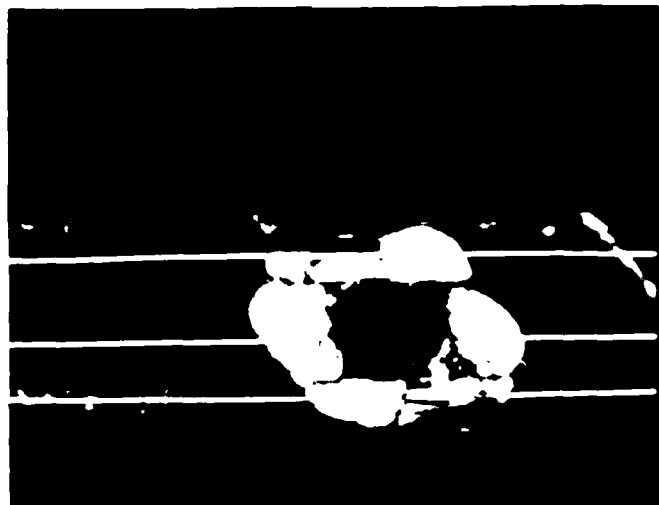
10X



C11-10-2

25X

LOCATION: 2.02 IN. DAMAGE LENGTH: NO DAMAGE



1

2

3

C-SCAN



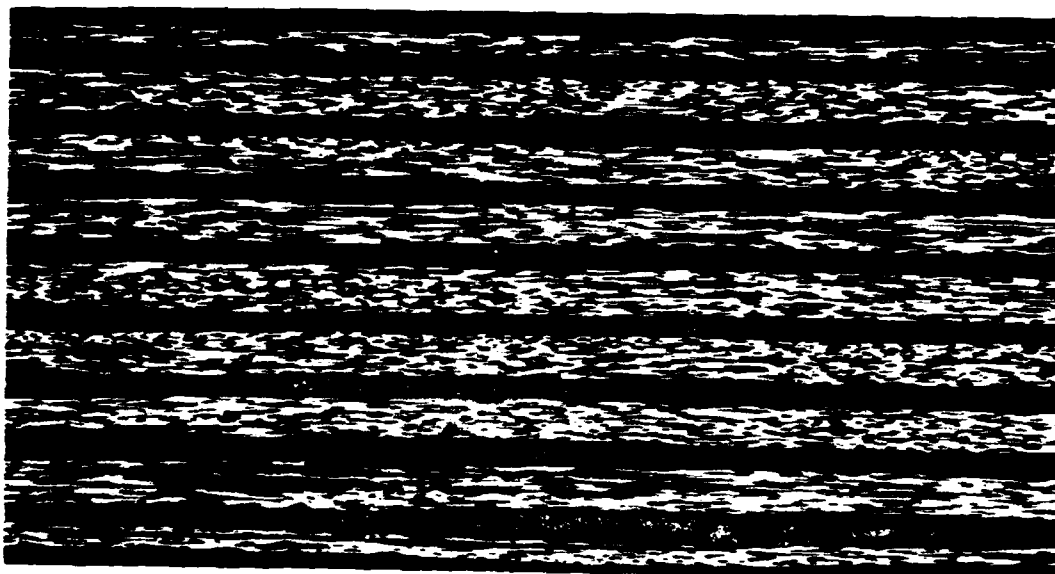
CUMULATIVE E-SCAN

SPEC: D-19 $N_3 = 12,000$ CYCLES



D19-1-1

10x



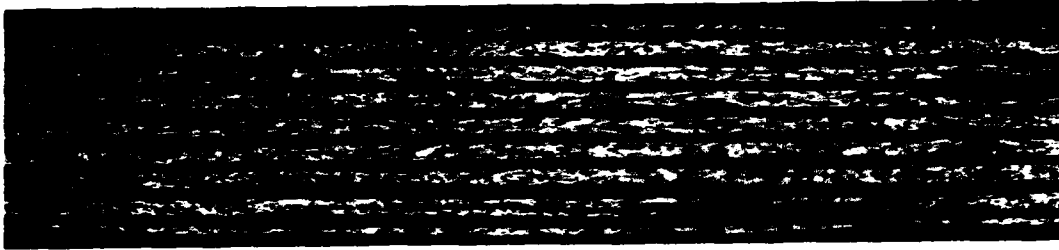
D19-1-2

25x

LOCATION: 1.15 IN. DAMAGE LENGTH: 0.659 IN.

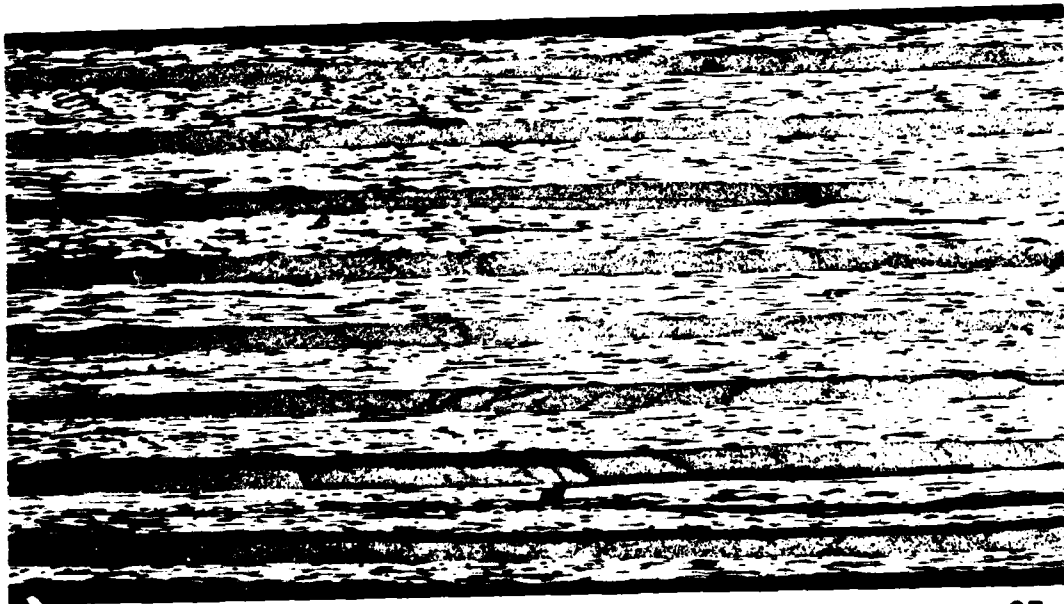


B-SCAN
@1.12 IN.



D19-2-1

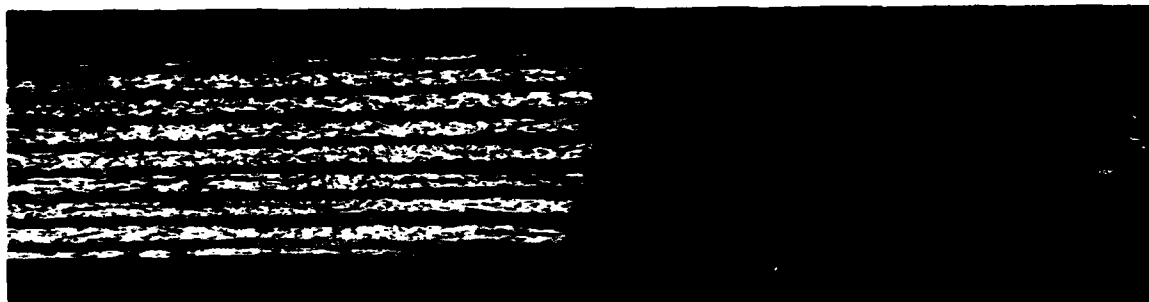
10x



D19-2-2

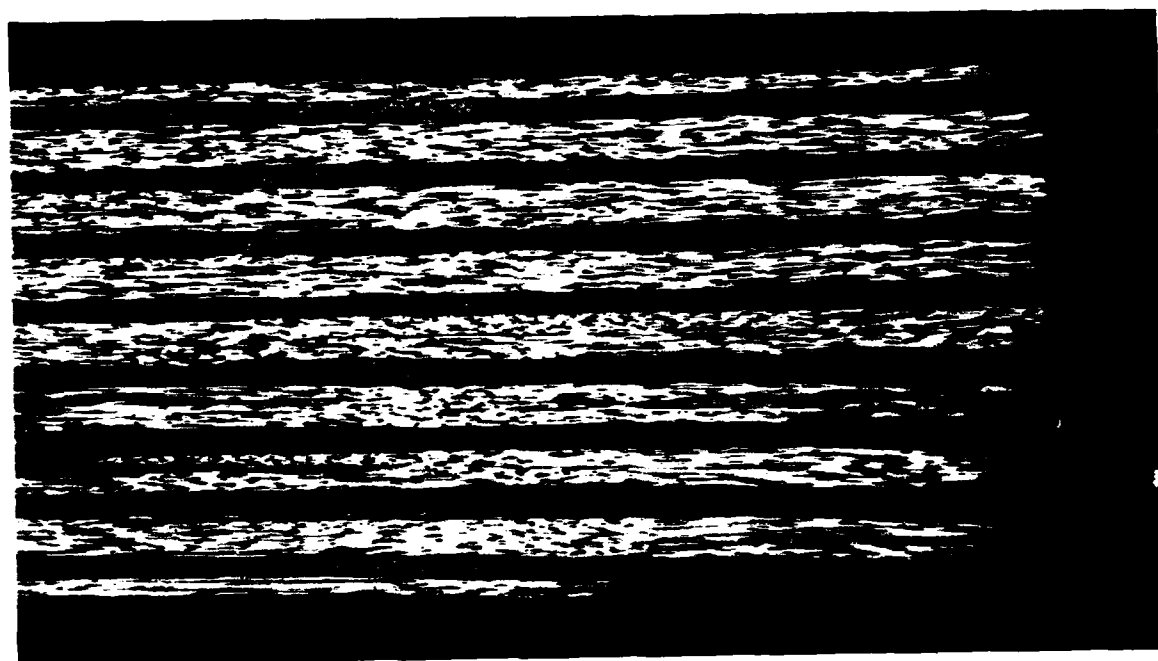
25x

LOCATION: 1.25 IN. DAMAGE LENGTH 0.858 IN.



D19-3-1A

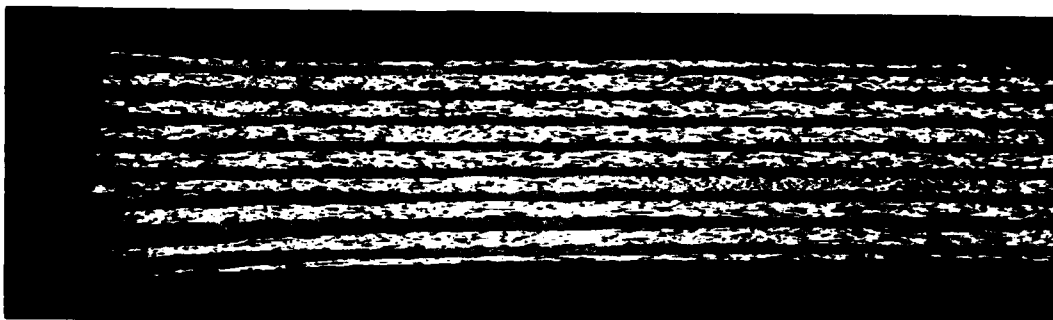
10x



D19-3-2A

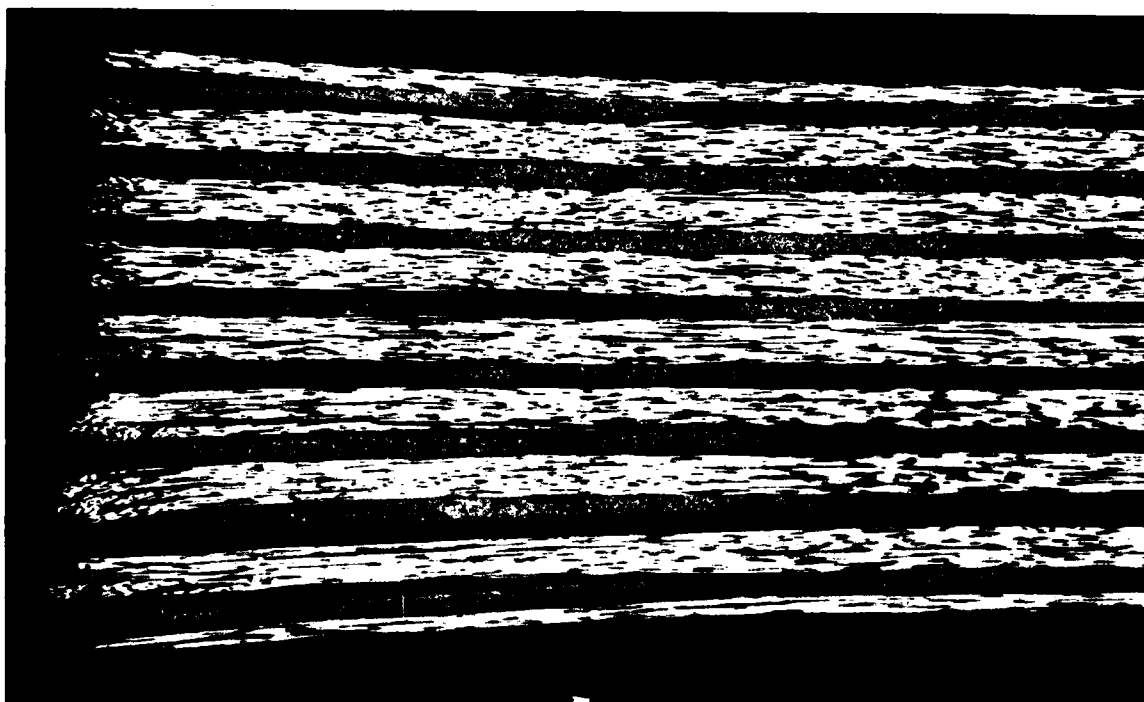
25x

LOCATION: 1.35 IN. DAMAGE LENGTH 0.908 IN.



D19-3-1B

10x

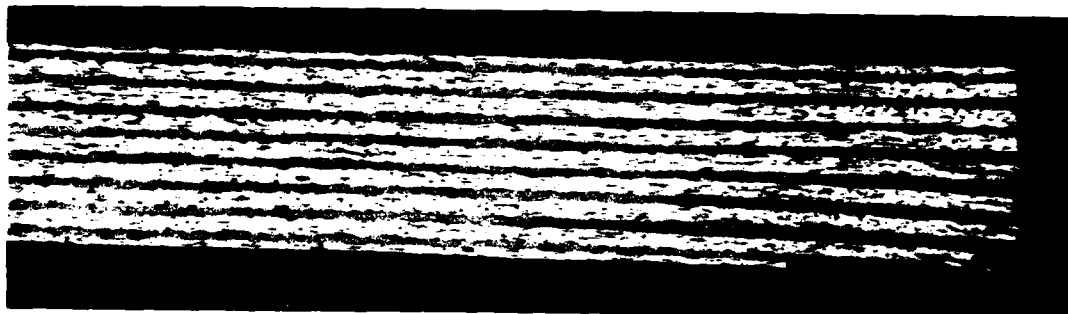


D19-3-2B

25x

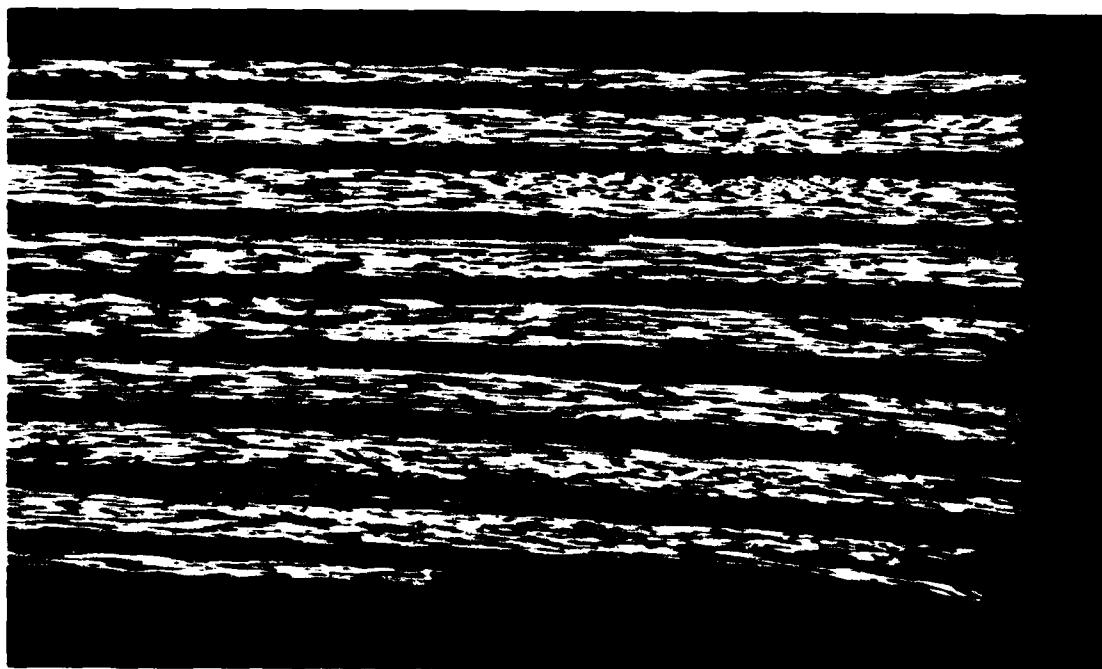
LOCATION: 1.35 IN. DAMAGE LENGTH 0.908 IN.

G21



D19-4-1A

10x



D19-4-2A

25x

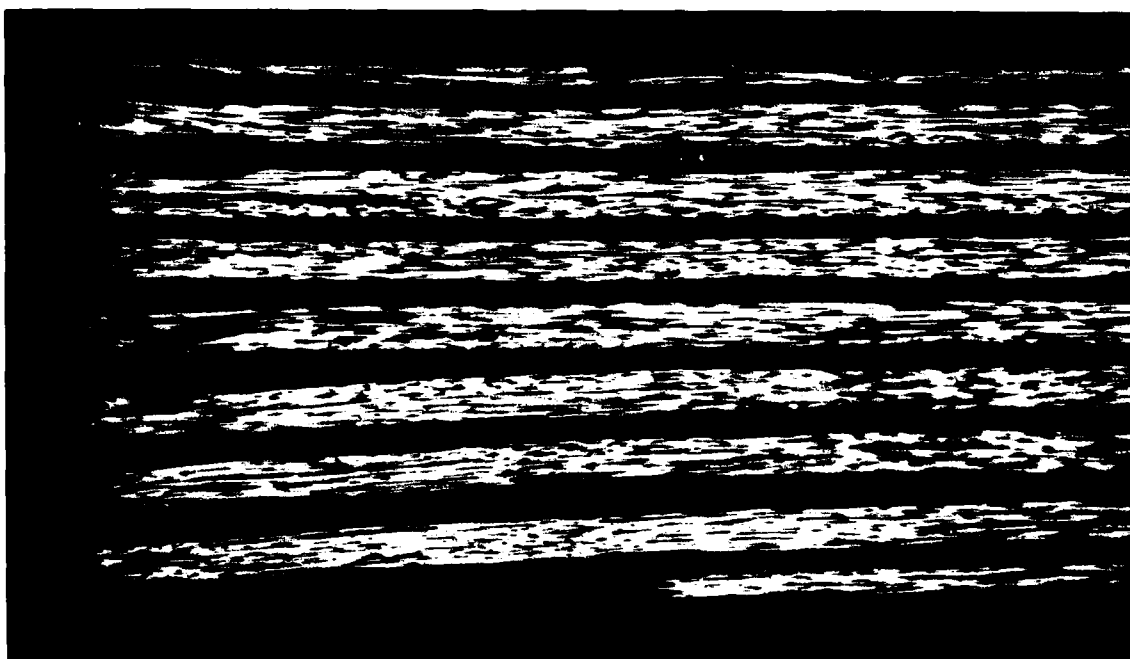
LOCATION: 1.45 IN. DAMAGE LENGTH 1.007 IN.

G22



D19-4-1B

10x



D19-4-2B

25x

LOCATION: 1.45 IN. DAMAGE LENGTH 1.007 IN.



D19-5-1A

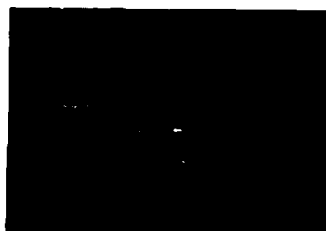
10x



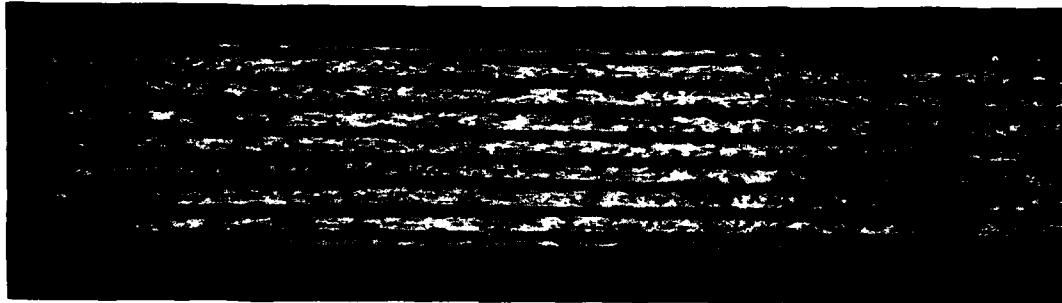
D19-5-2A

25x

LOCATION: 1.55 IN. DAMAGE LENGTH: 0.988 IN.

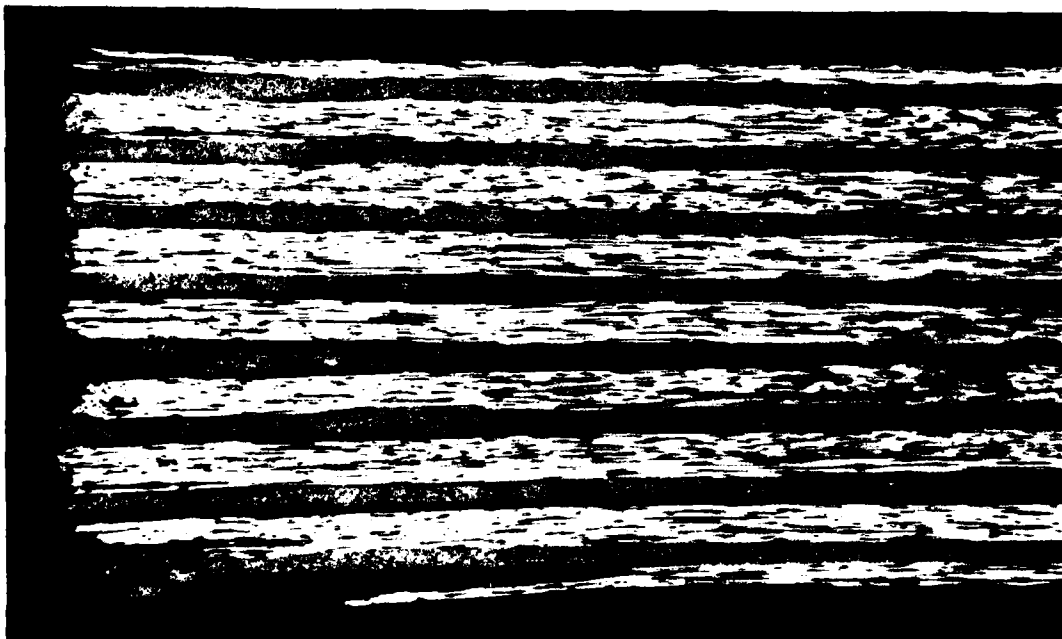


B-SCAN
@ 1.5 IN.



D19-5-1B

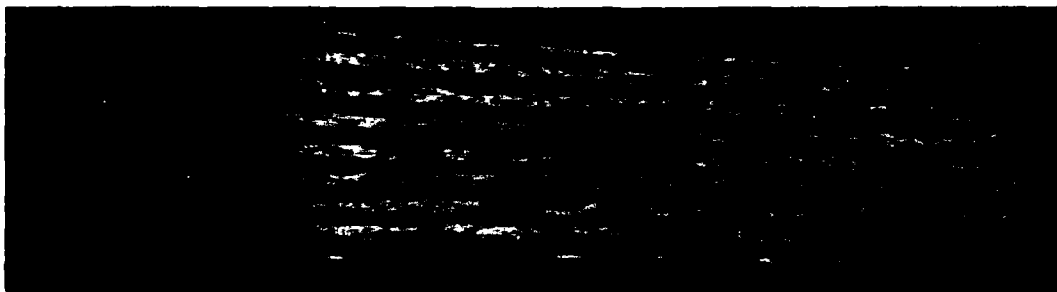
10x



D19-5-2B

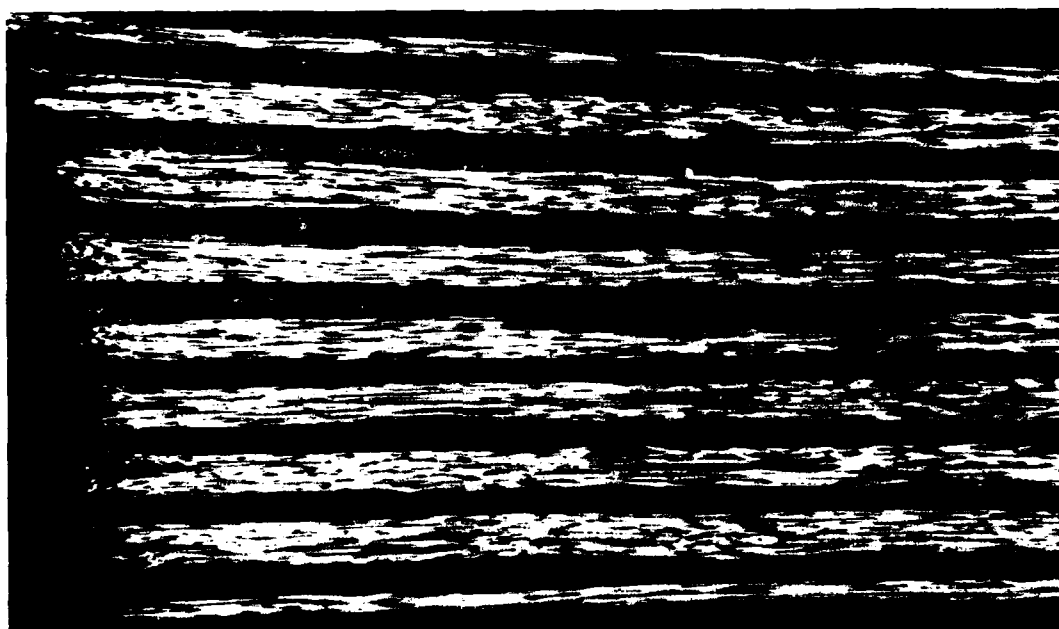
25x

LOCATION: 1.55 in. DAMAGE LENGTH 0.985 in.



D19-6-1A

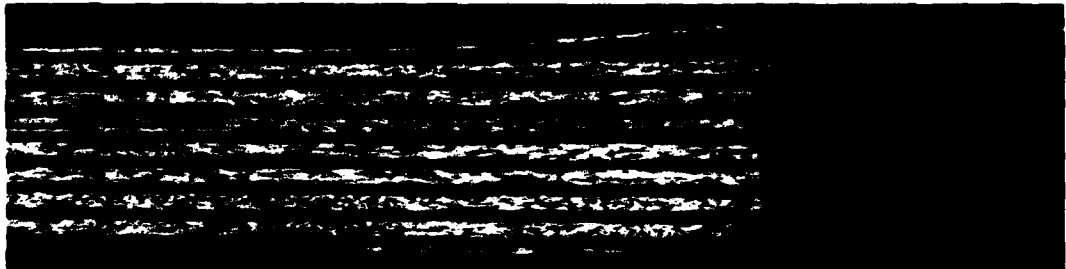
10X



D19-6-2A

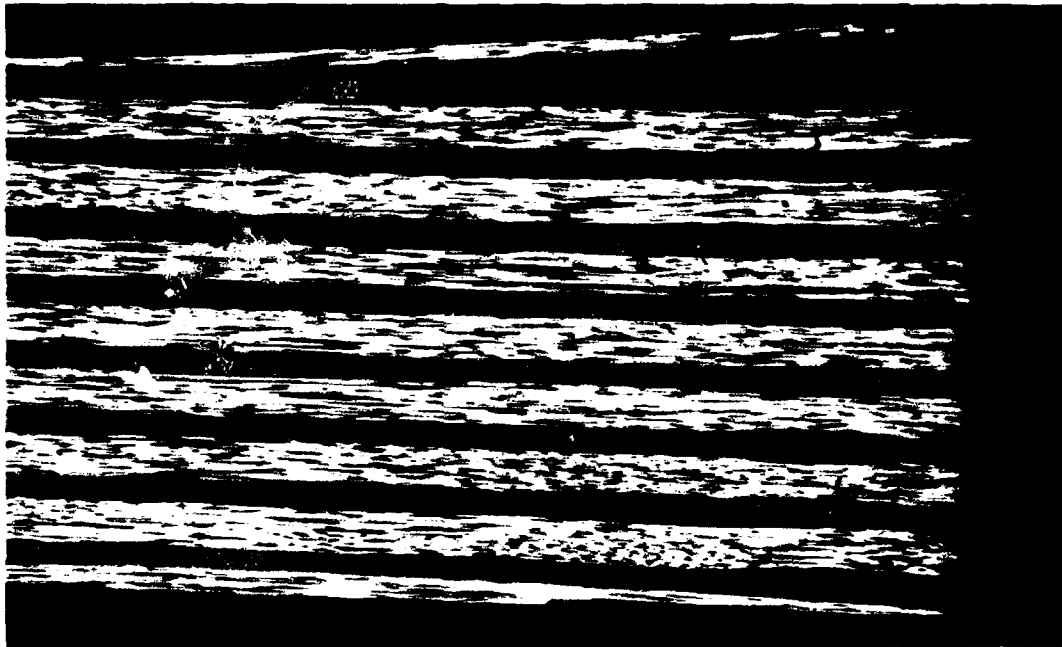
25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918



D19-6-1B

10X



D-19-6-2B

25X

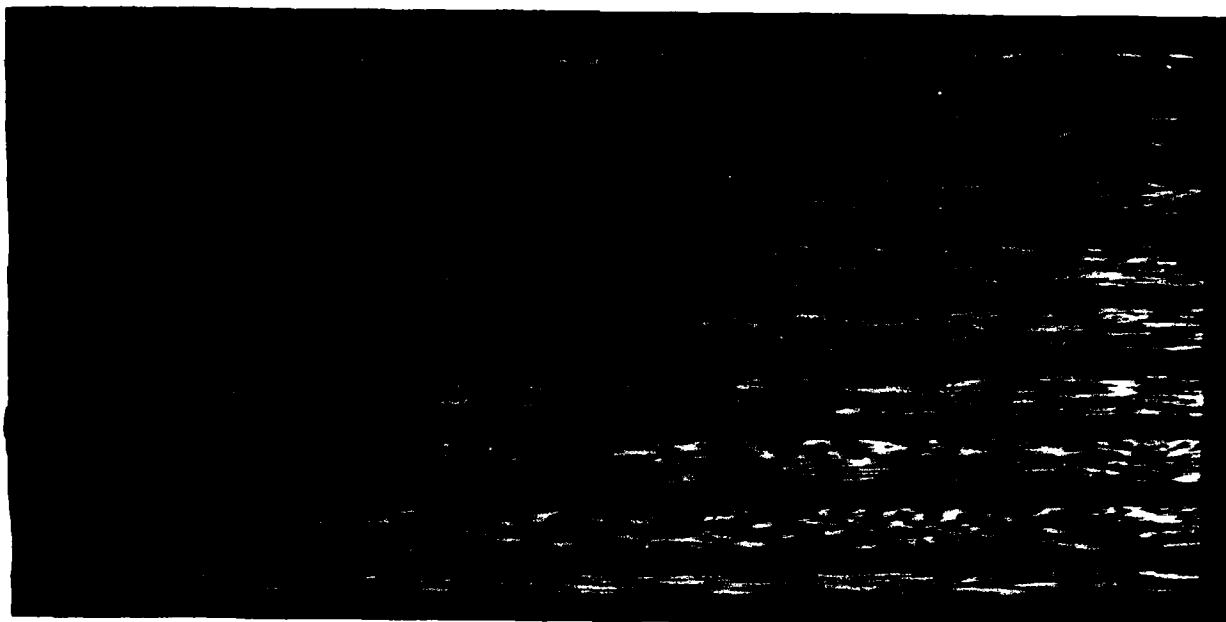
LOCATION: 1.48 in. DAMAGE LENGTH: 0.918

G27



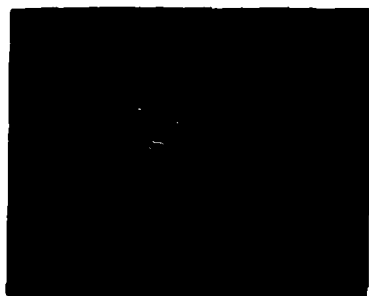
D19-7-1

10X



D19-7-2

25X



B-SCAN AT 1.78 IN.

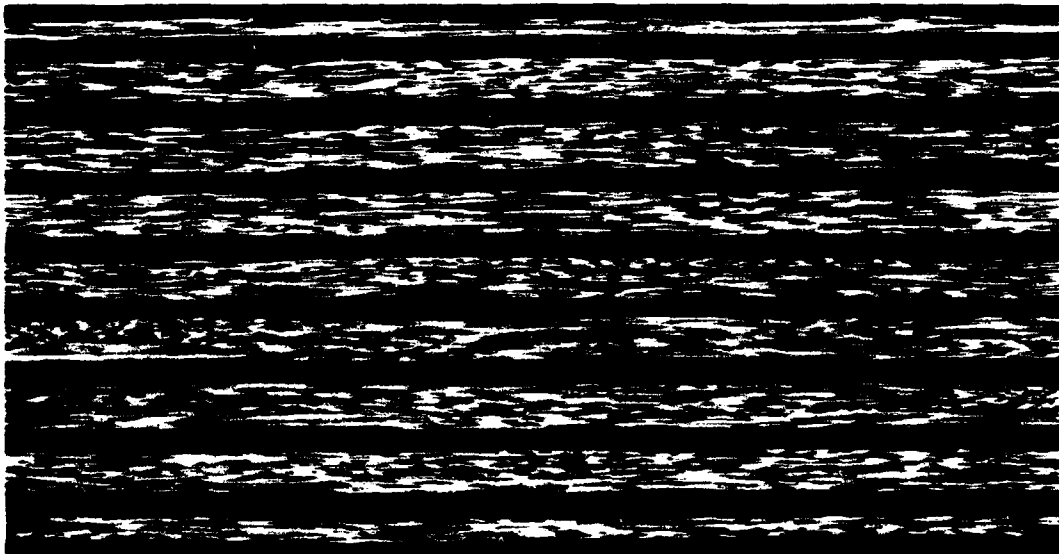
LOCATION: 1.75 IN. DAMAGE LENGTH: 0.710

G28



D19-8-1

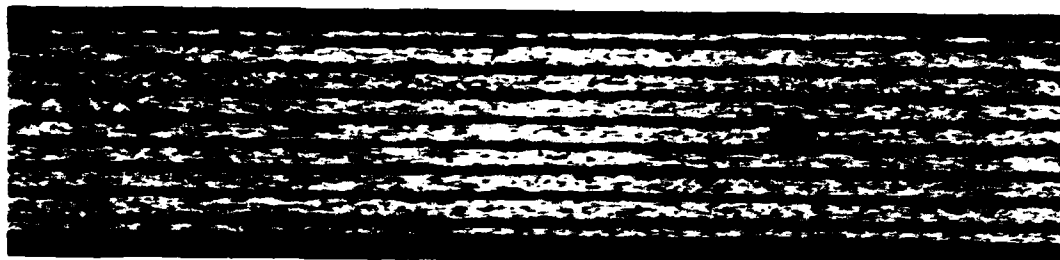
10X



D-19-8-2

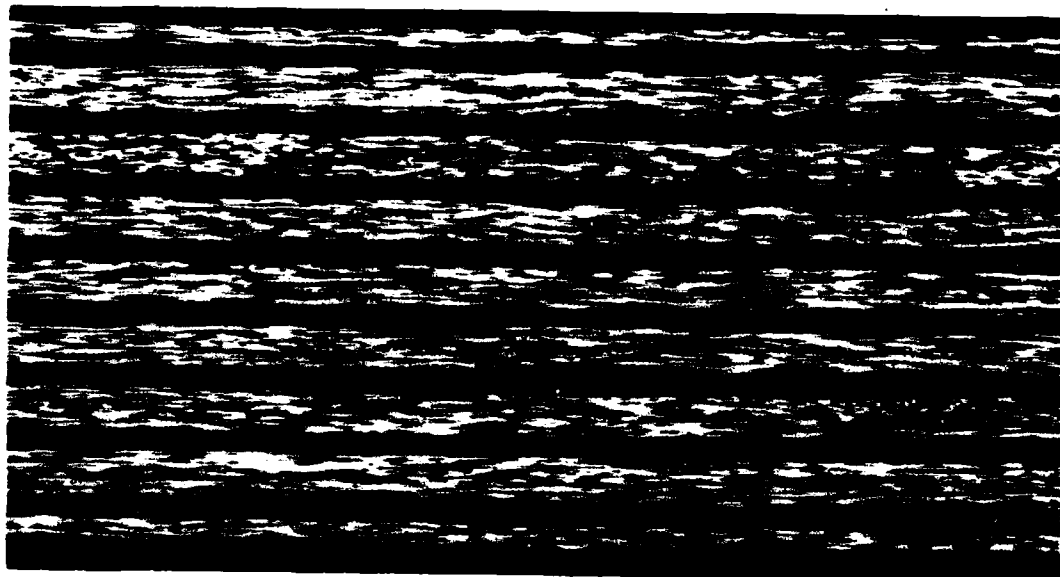
25X

LOCATION: 1.68 in. DAMAGE LENGTH: 0.933



D19-9-1

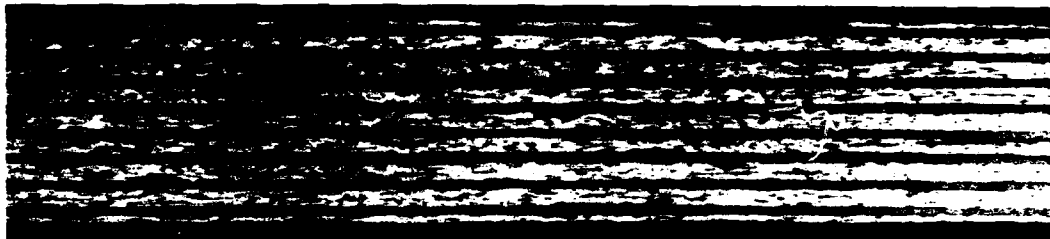
10X



D-19-9-2

25X

LOCATION: 1.78 in. DAMAGE LENGTH: 0.888



D19-10-1

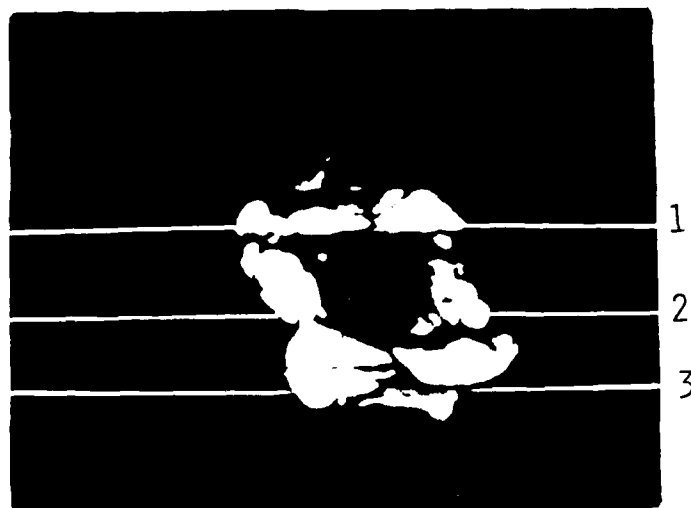
10X



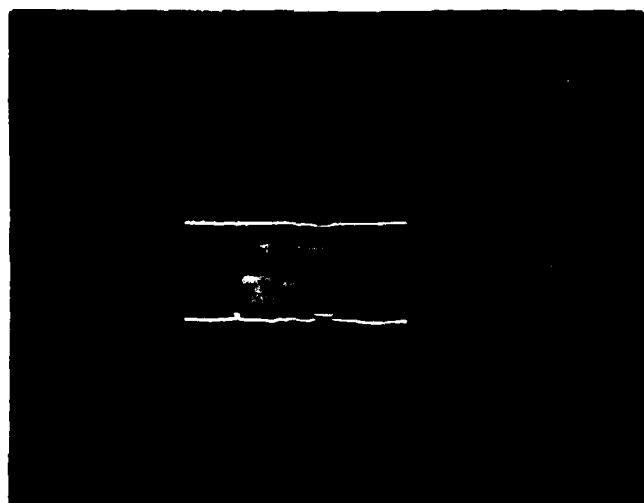
D-19-10-2

25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.630

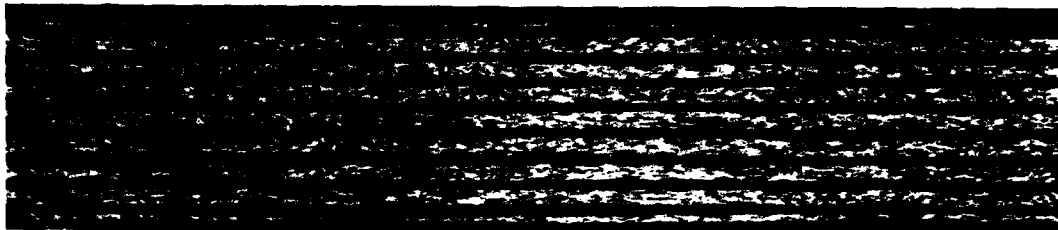


C-SCAN



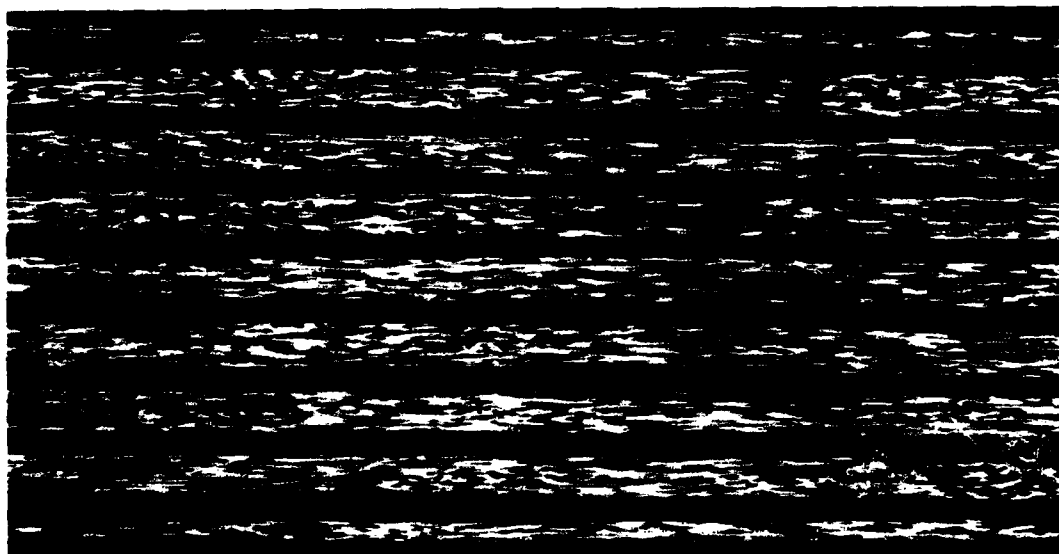
CUMULATIVE B-SCAN

24-PLY SPEC: IB-12 $N_4 = 20,000$ CYCLES.



I12-1-1

10X



I12-1-2

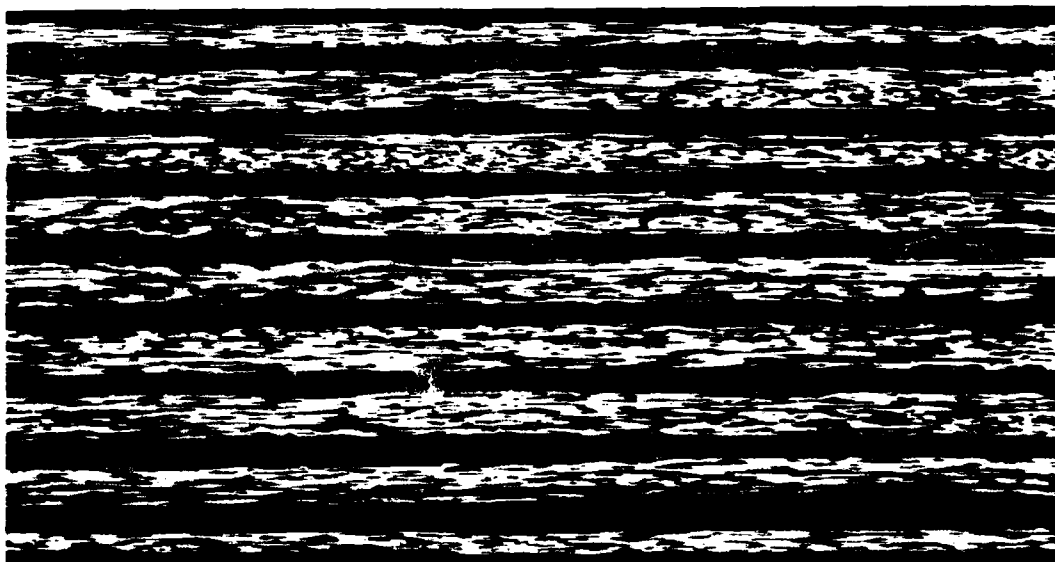
25X

LOCATION: 1.08 in. DAMAGE LENGTH: 0.439



I12-2-1

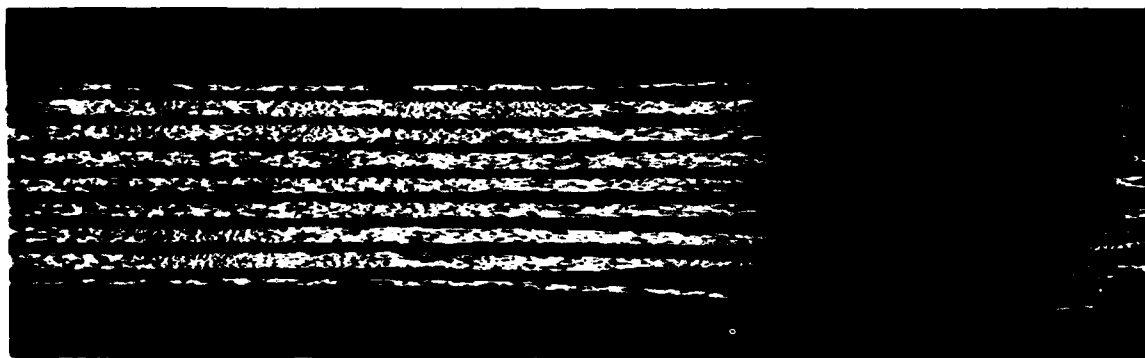
10X



I12-2-2

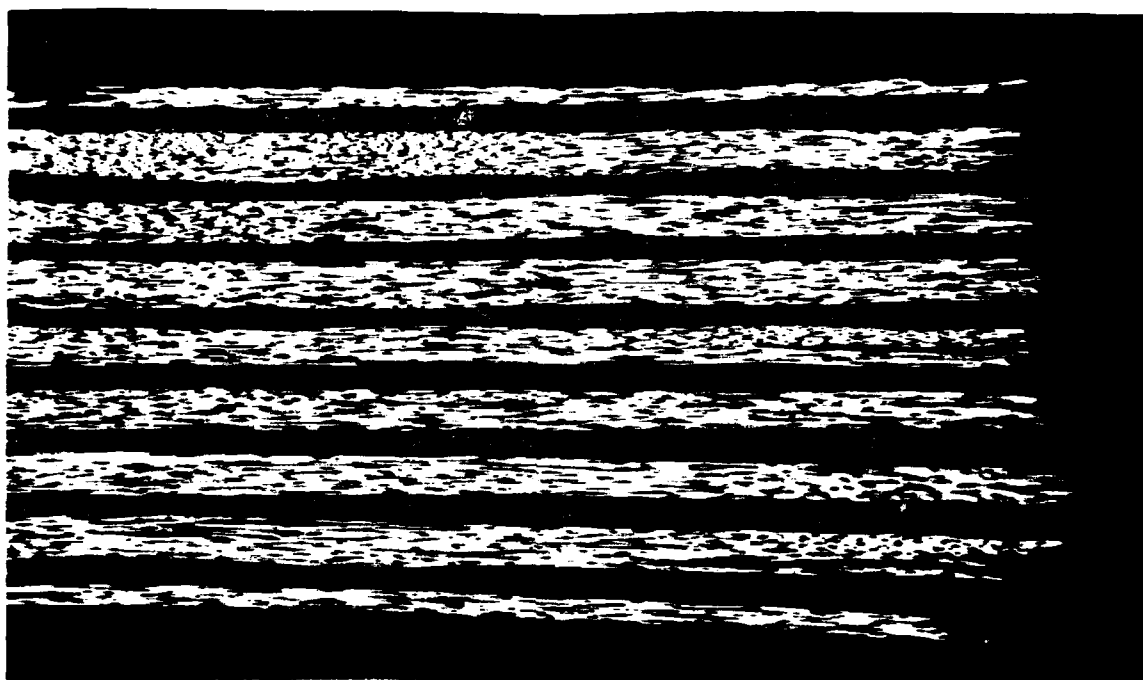
25X

LOCATION: 1.22IN. DAMAGE LENGTH: 0.704



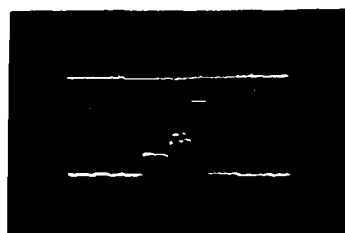
I12-3-1A

10X



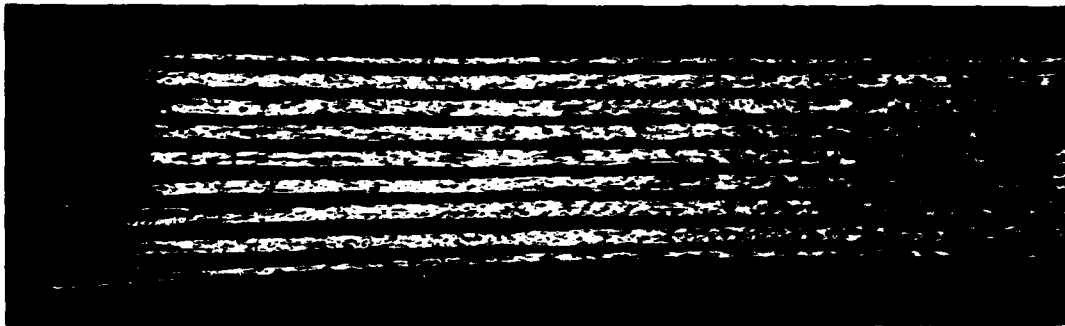
I12-3-2A

25X



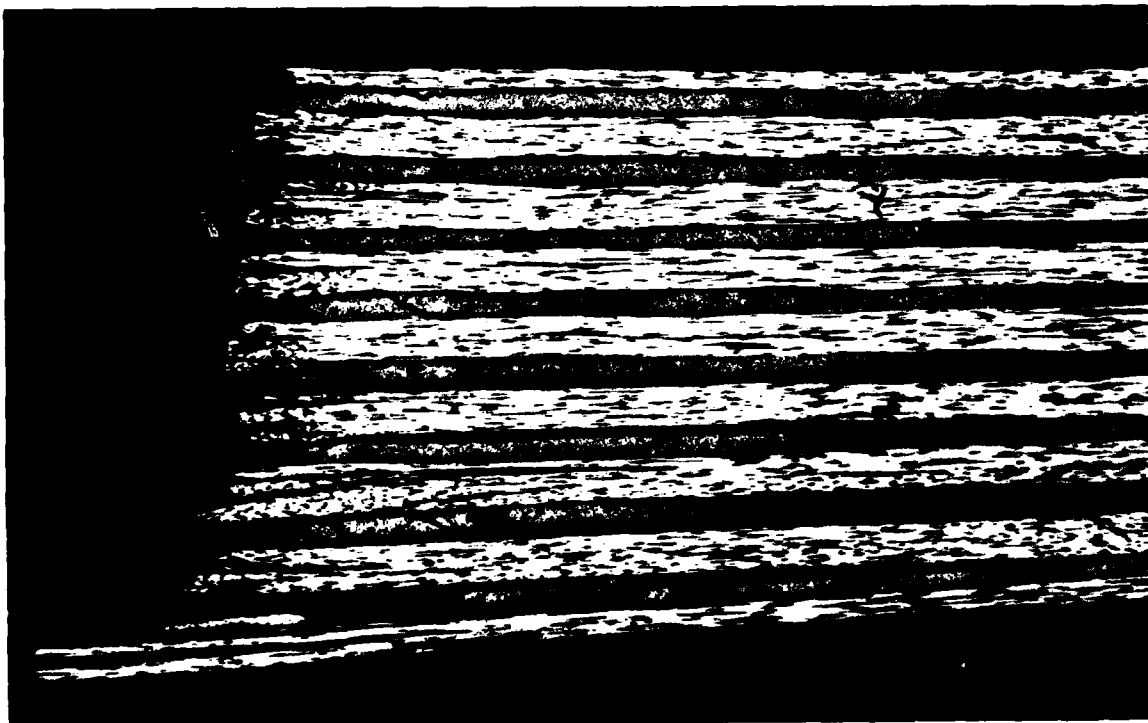
B-SCAN AT 1.23 IN.

LOCATION: 1.28 IN. DAMAGE LENGTH: 0.868



I12-3-1B

10X

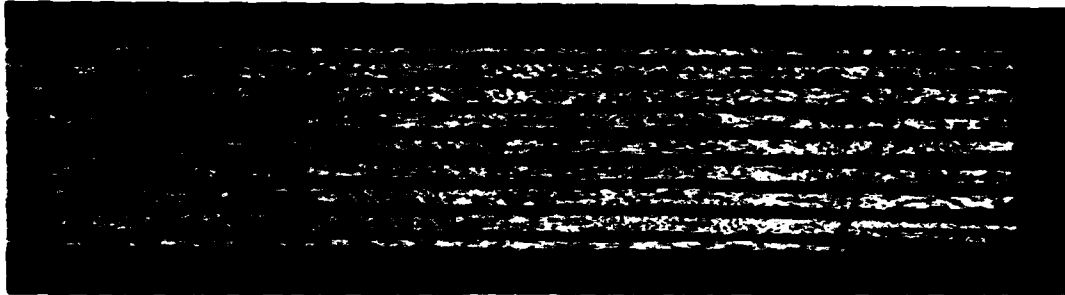


I12-3-2B

25X

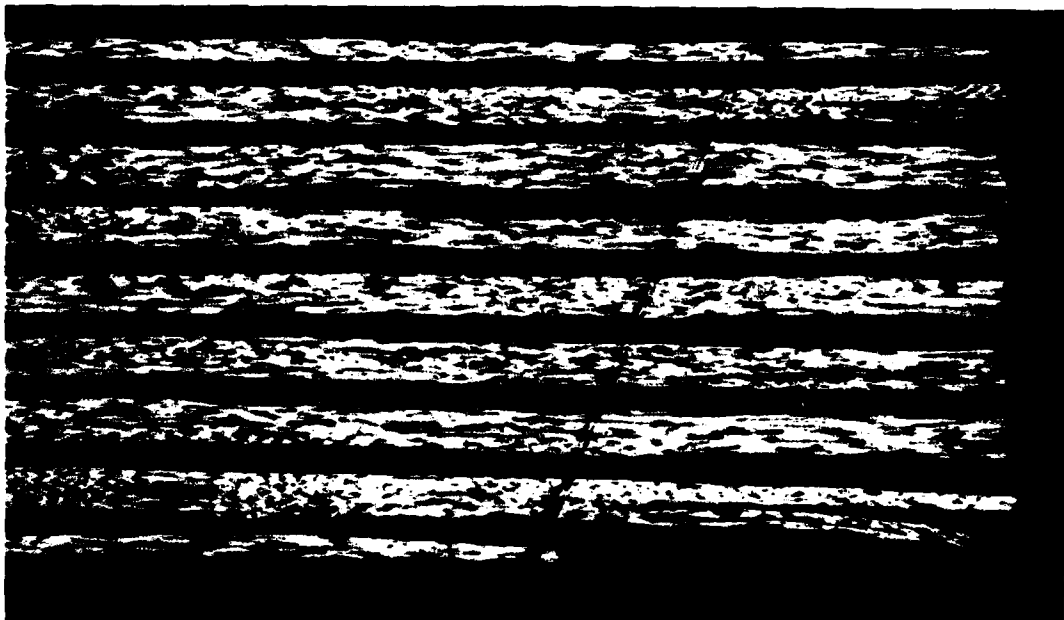
LOCATION: 1.28 in. DAMAGE LENGTH: 0.868

G36



I12-4-1A

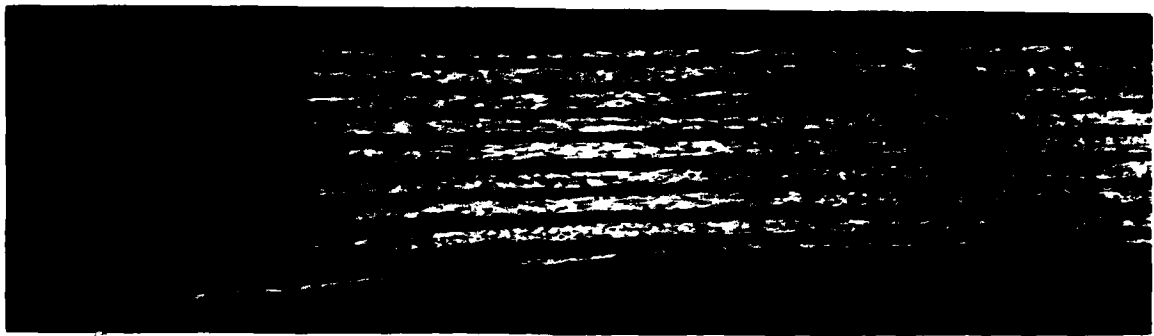
10X



I12-4-2A

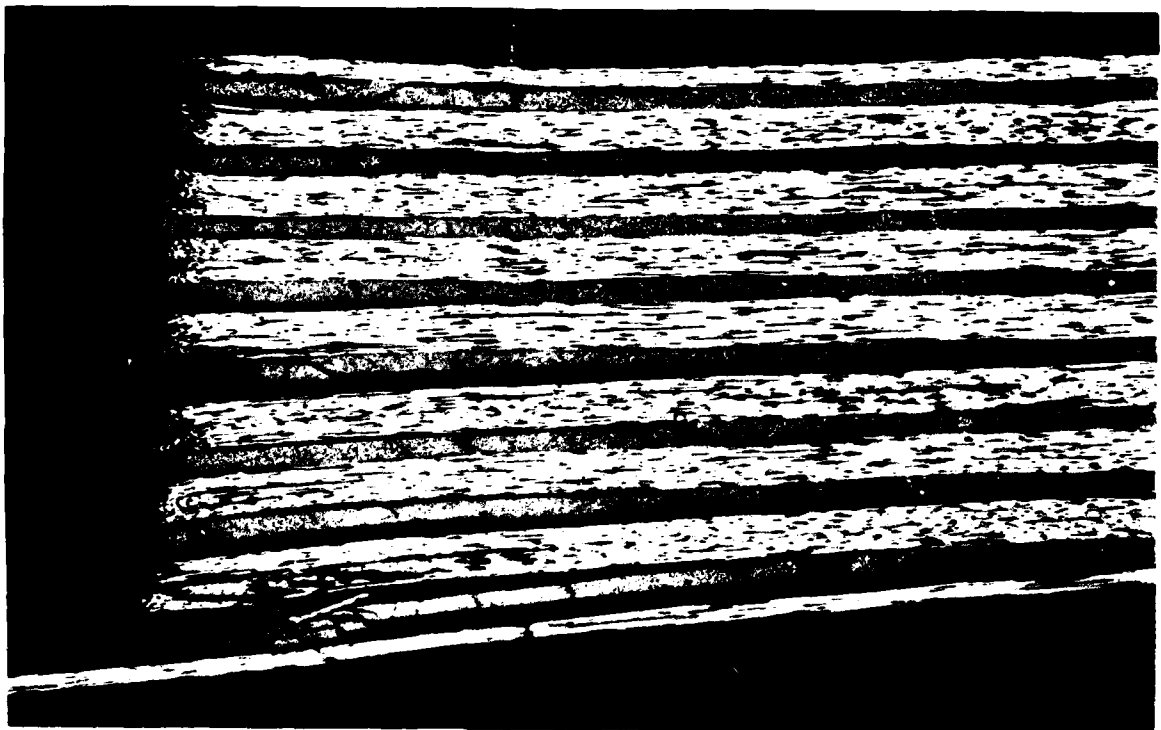
25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.856



I12-4-1B

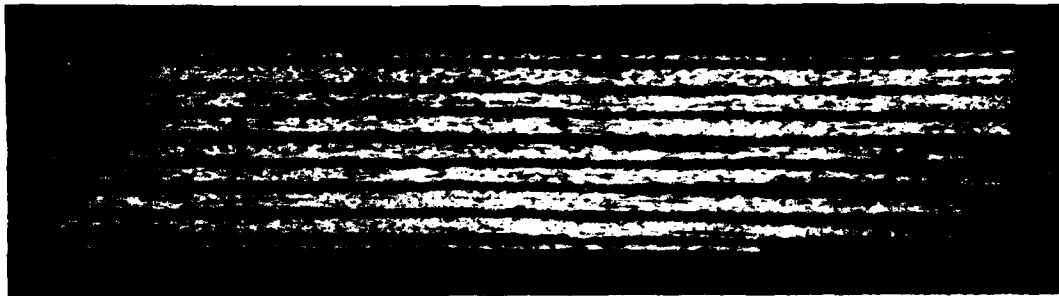
10X



I12-4-2B

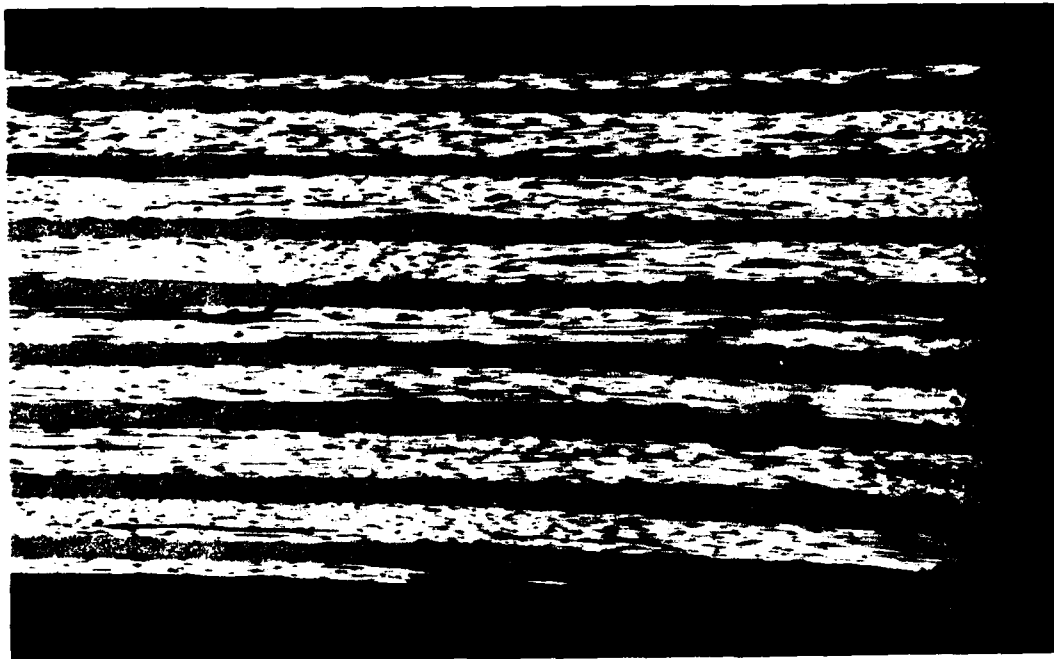
25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.856



I12-5-1A

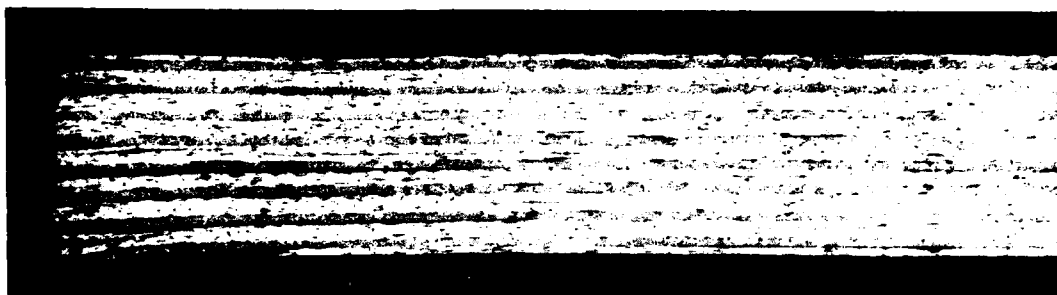
10X



I12-5-2A

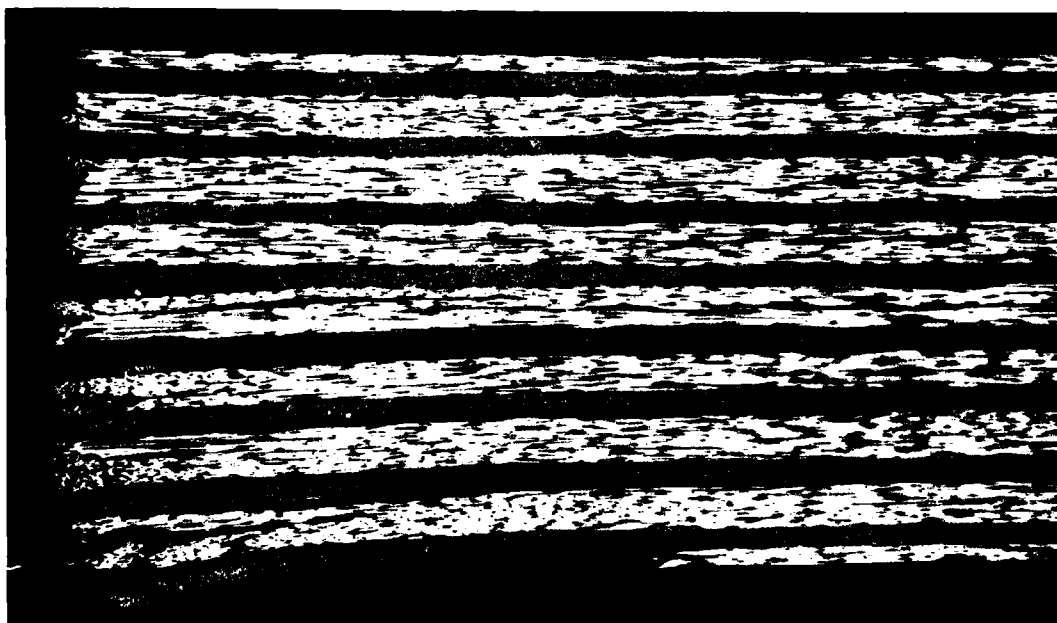
25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.997



I12-5-1B

10X



I12-5-2B

25X

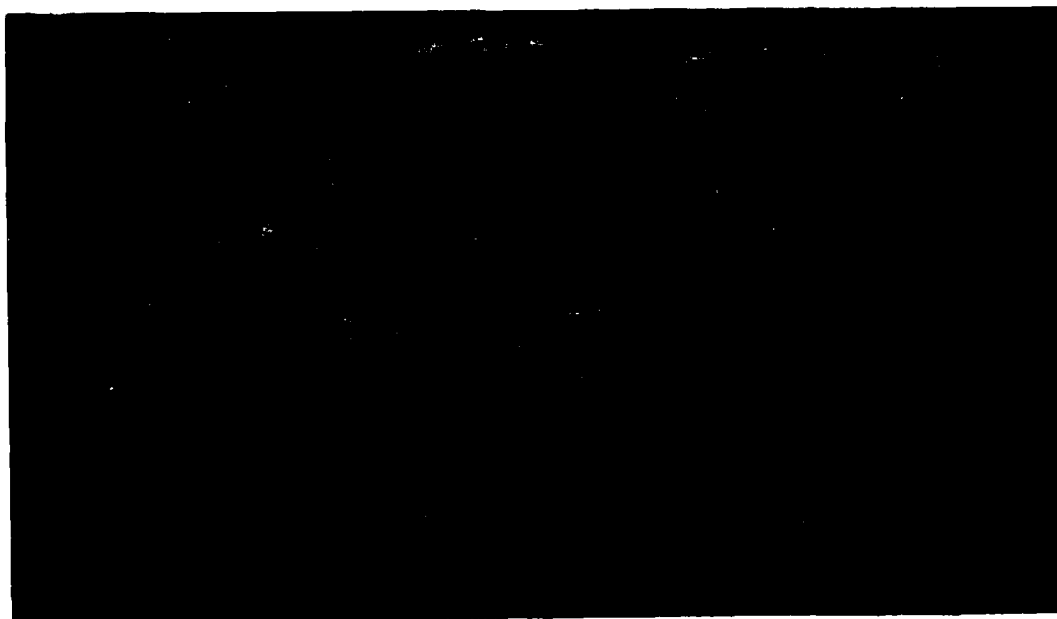
LOCATION: 1.48 IN. DAMAGE LENGTH: 0.997

G40



I12-6-1A

10X



I12-6-2A

25X

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.869



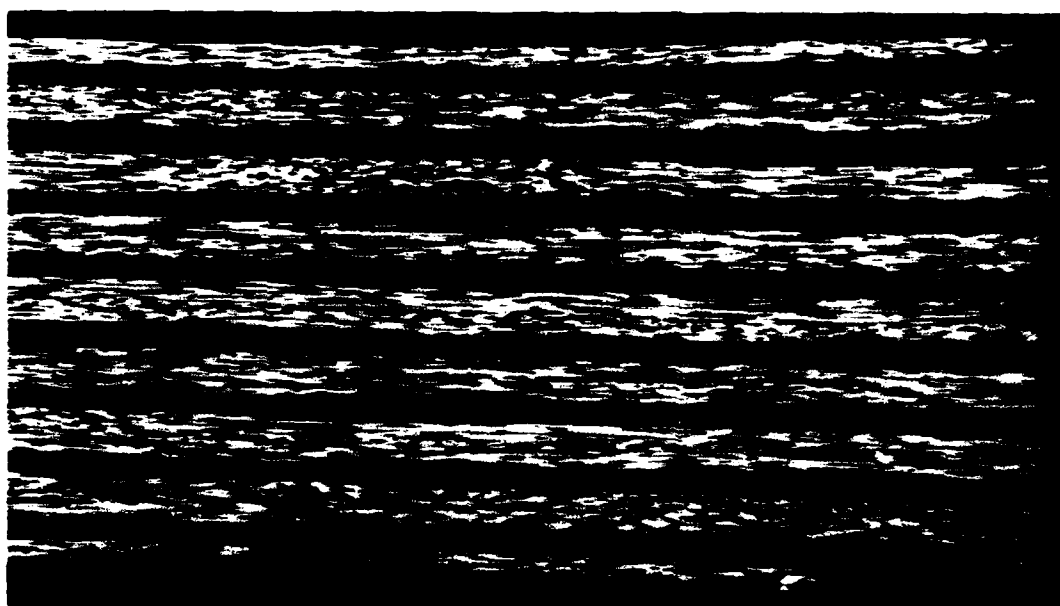
B-SCAN AT 1.59 IN.

G41



I12-6-1B

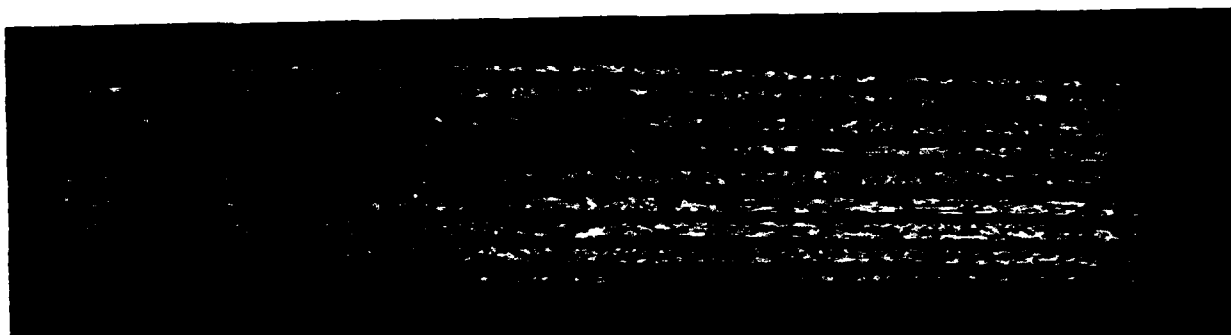
10X



I12-6-2B

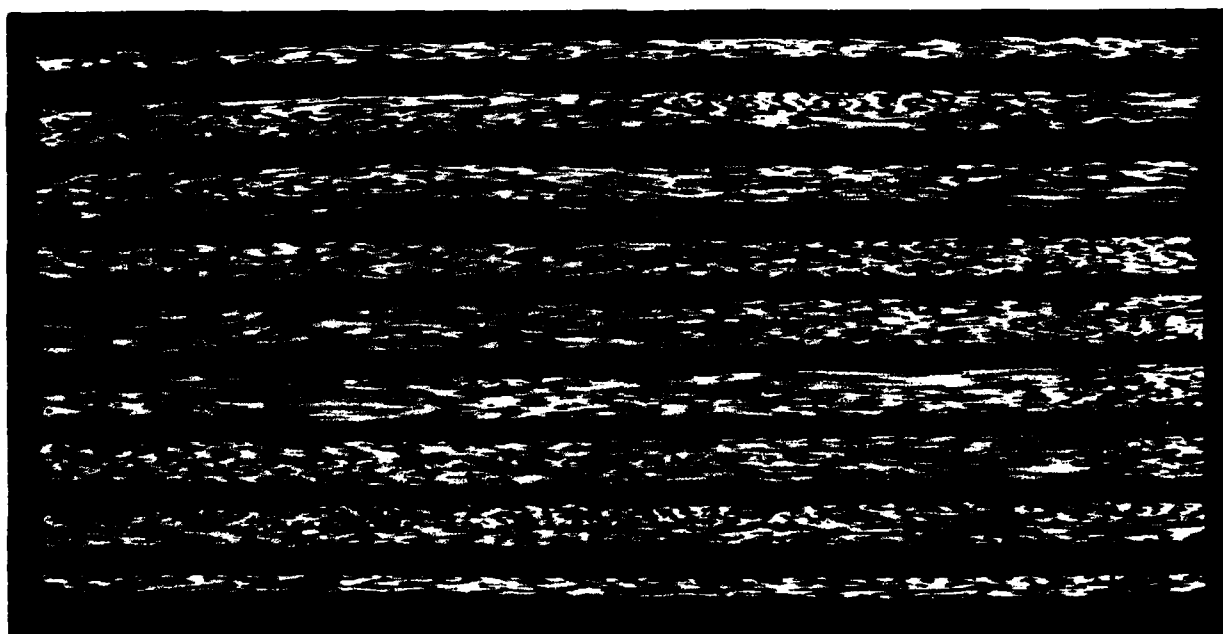
25X

LOCATION: 1.58 IN. DAMAGE LENGTH: 0.869



I12-7-1

10X



I12-7-2

25X

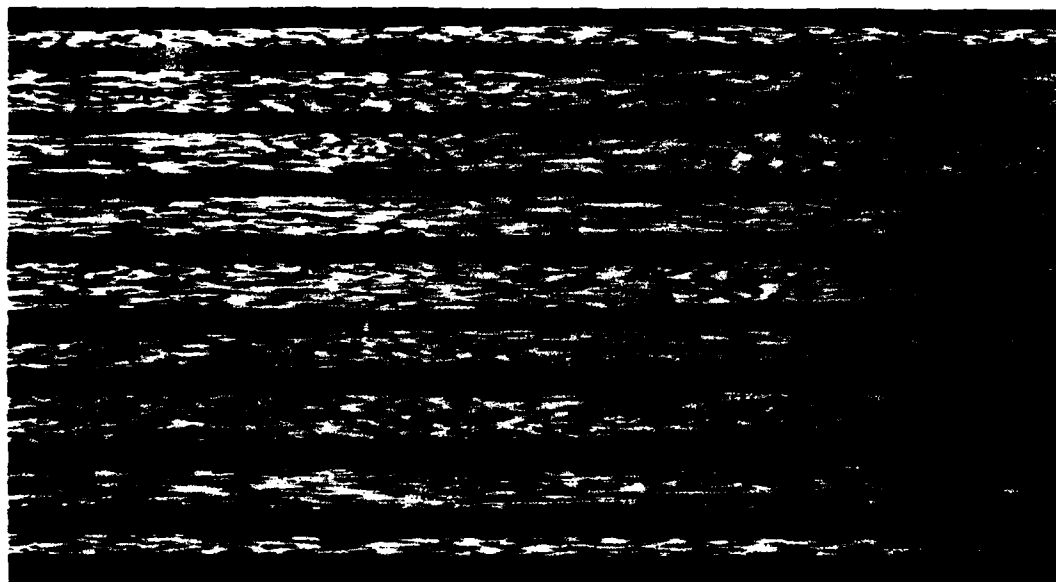
LOCATION: 1.68 IN. DAMAGE LENGTH: 0.973

G43



I12-8-1

10X



I12-8-2

25X

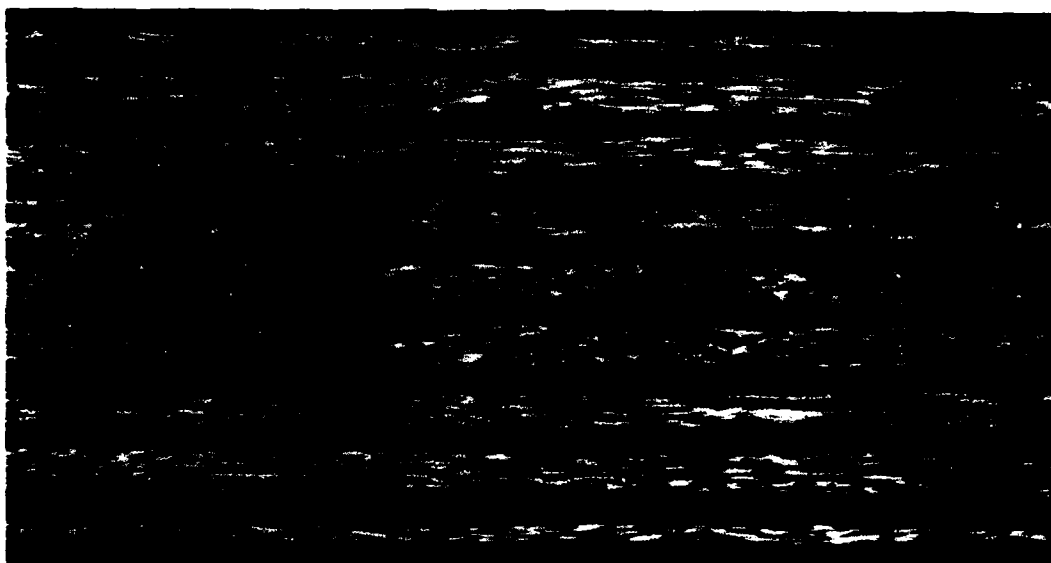
LOCATION: 1.78 in. DAMAGE LENGTH: 0.907

G44



I12-9-1

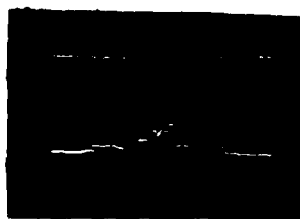
10X



I12-9-2

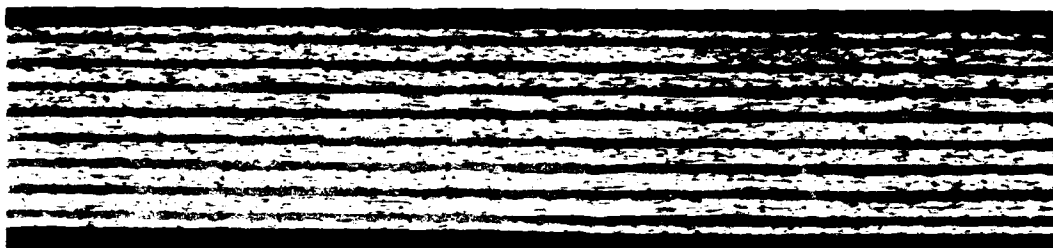
25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.702



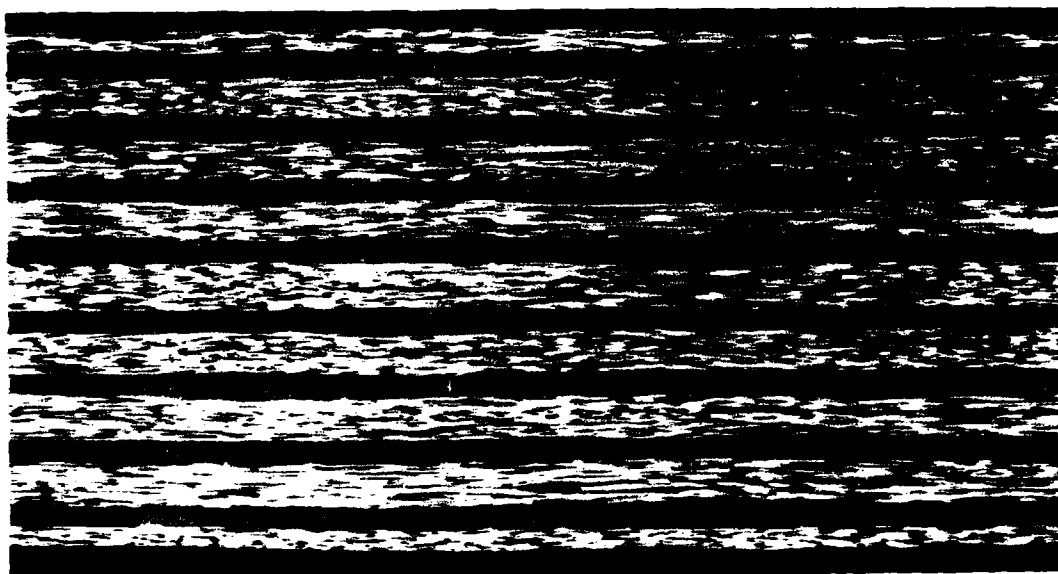
B-SCAN AT 1.88 IN.

G45



I12-10-1

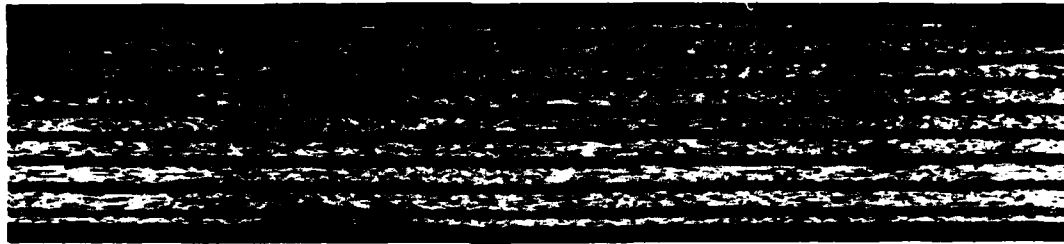
10X



I12-10-2

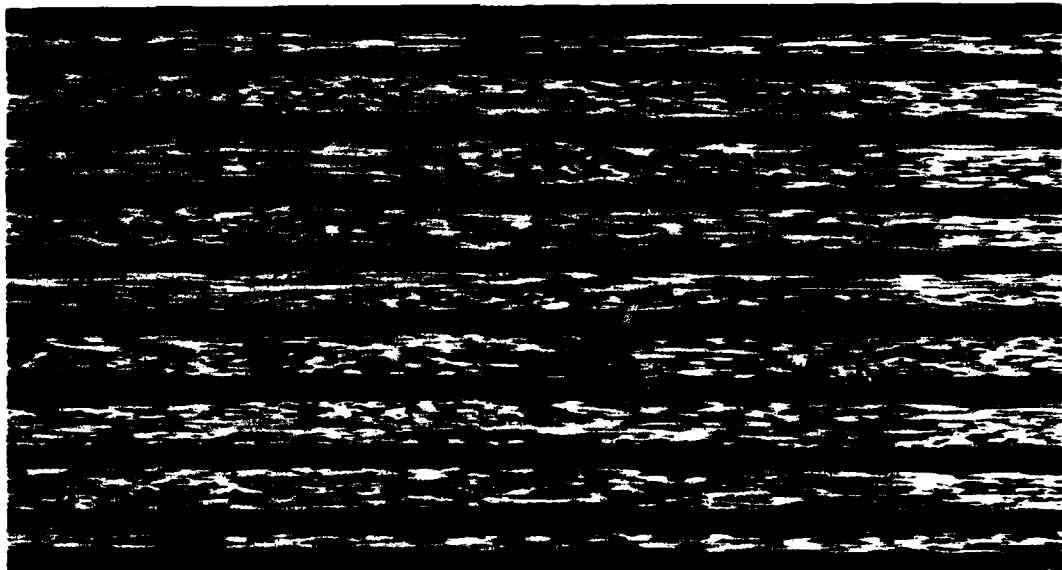
25X

LOCATION: 1.98 in. DAMAGE LENGTH: 0.204



I12-11-1

10X



I12-11-2

25X

LOCATION: 2.08 IN. DAMAGE LENGTH: No DAMAGE

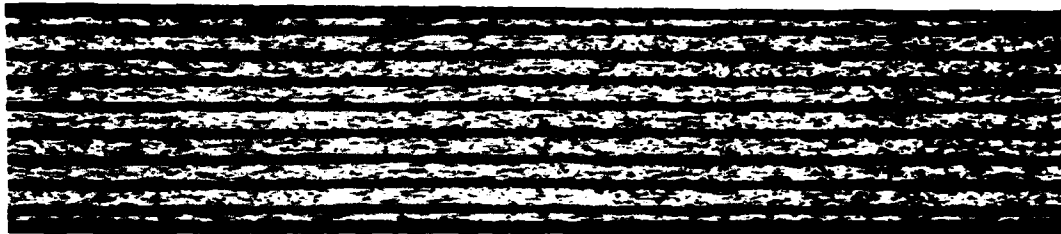


C-SCAN



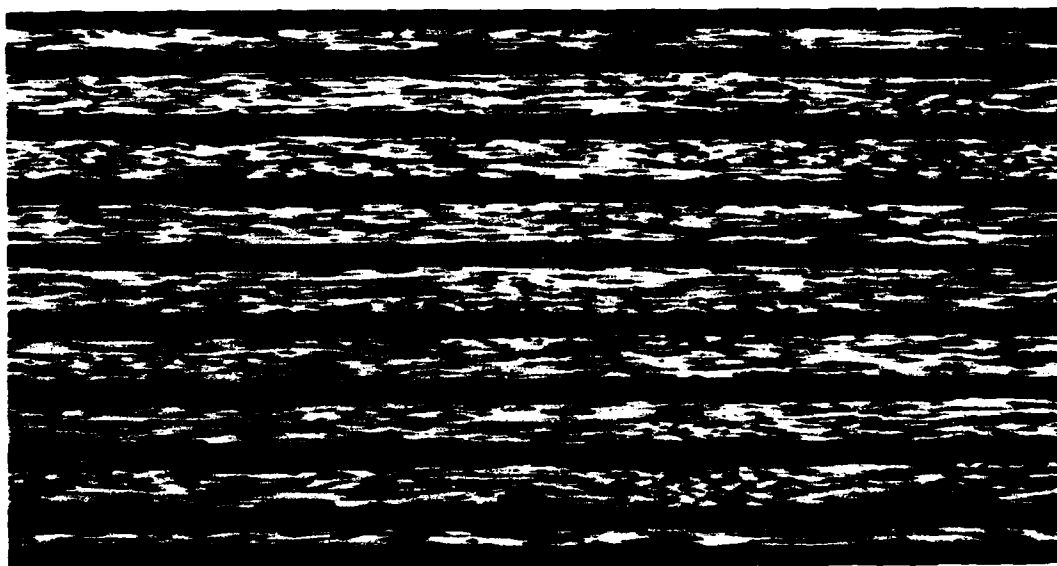
CUMULATIVE B-SCAN

24-PLY SPEC: EC-30 $N_5 = 40,000$



E30-1-1

10X



E30-1-2

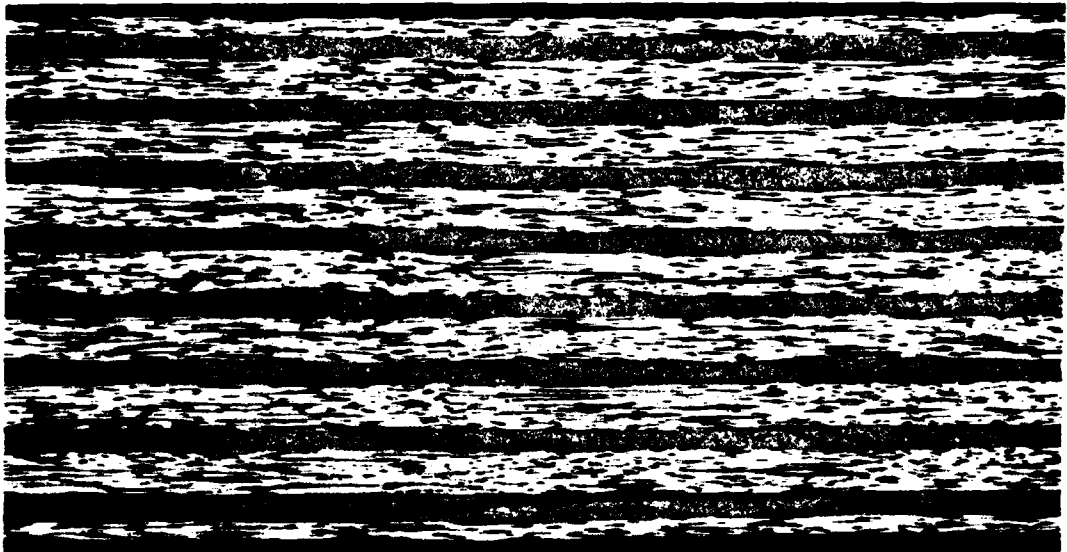
25X

LOCATION: 0.45 IN. DAMAGE LENGTH: NO CRACKS



E30-2-1

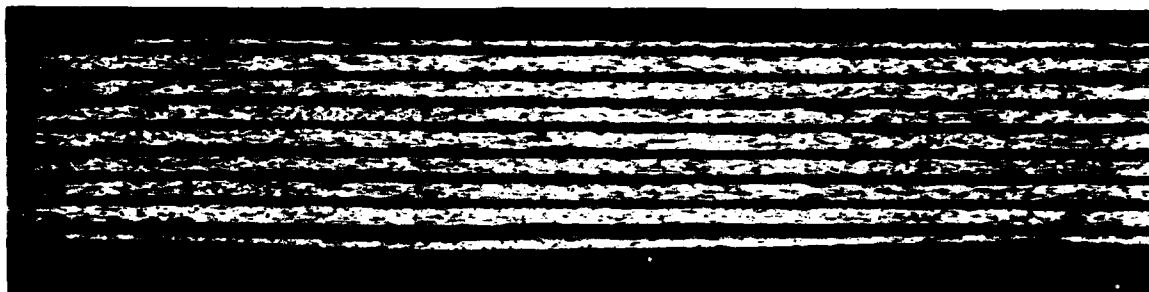
10X



E30-2-2

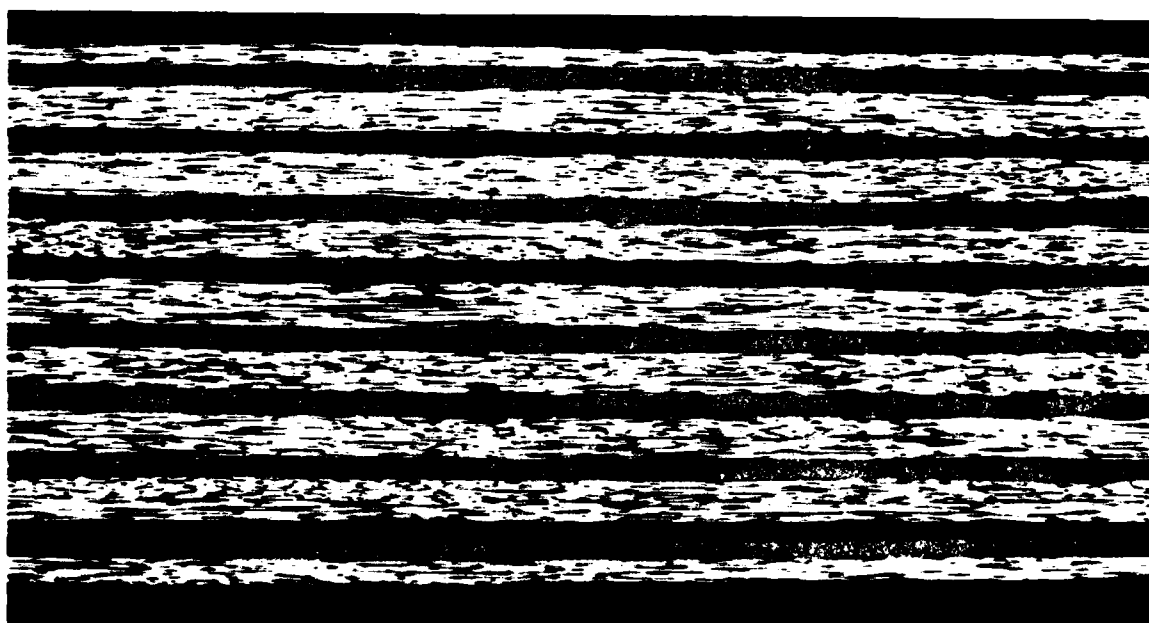
25X

LOCATION: 0.55 IN. DAMAGE LENGTH: 0.326



E30-3-1

10X



E30-3-2

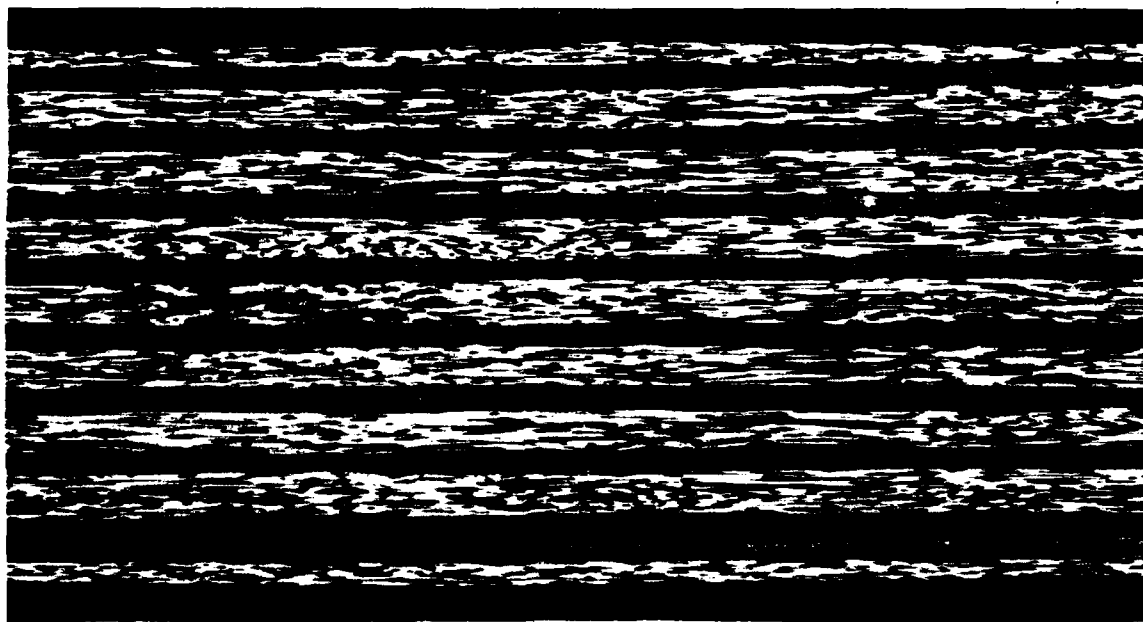
25X

LOCATION 0.65 IN. DAMAGE LENGTH: 0.616



E30-4-1

10X



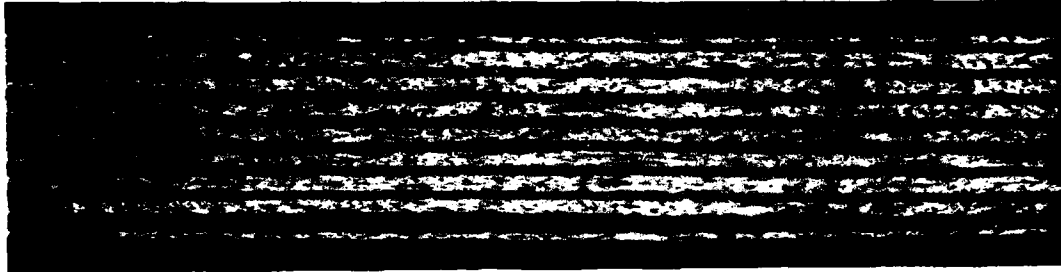
E30-4-2

25X



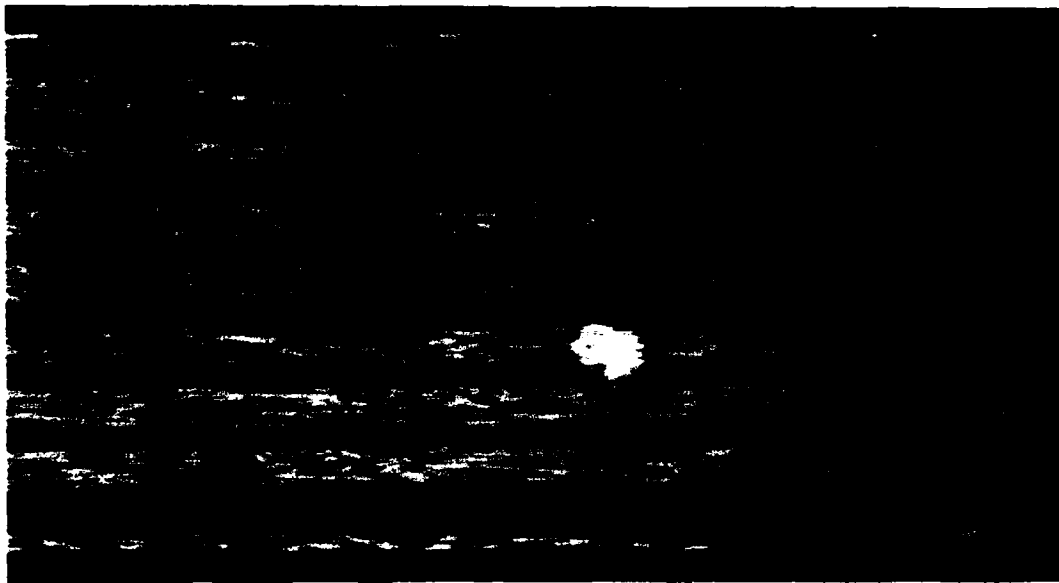
B-SCAN AT 1.79 IN.

LOCATION: 0.75 IN. DAMAGE LENGTH: 0.766



E30-5-1.

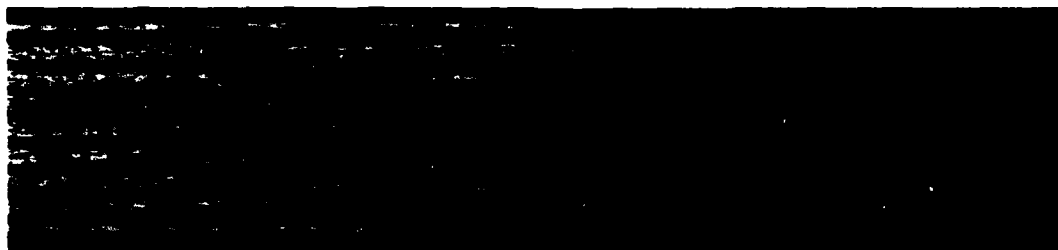
10X



E30-5-2

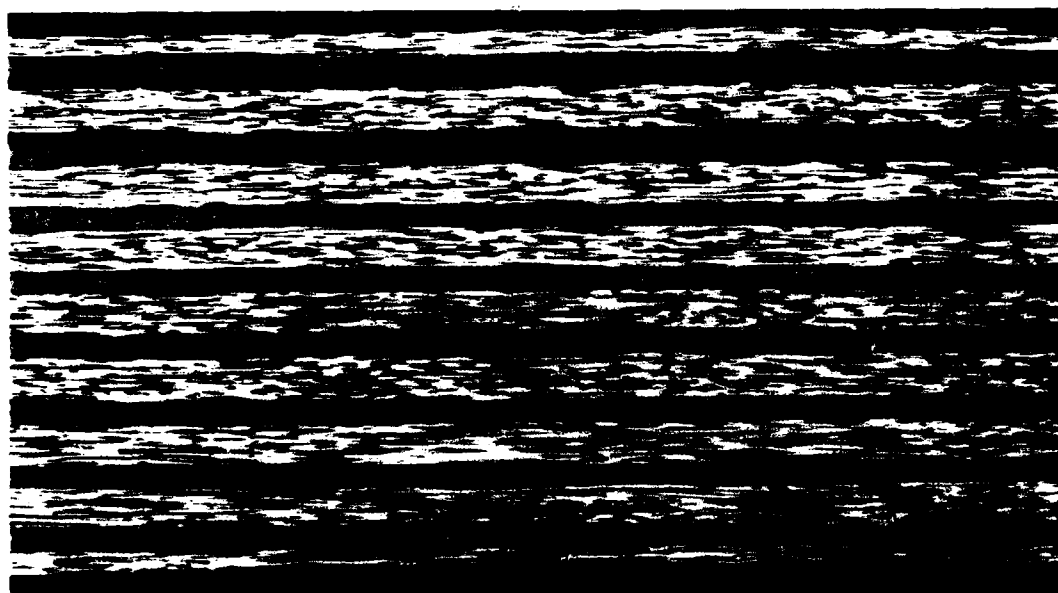
25X

LOCATION: 0.85 IN. DAMAGE LENGTH: 0.822



E30-6-1

10X



E30-6-2

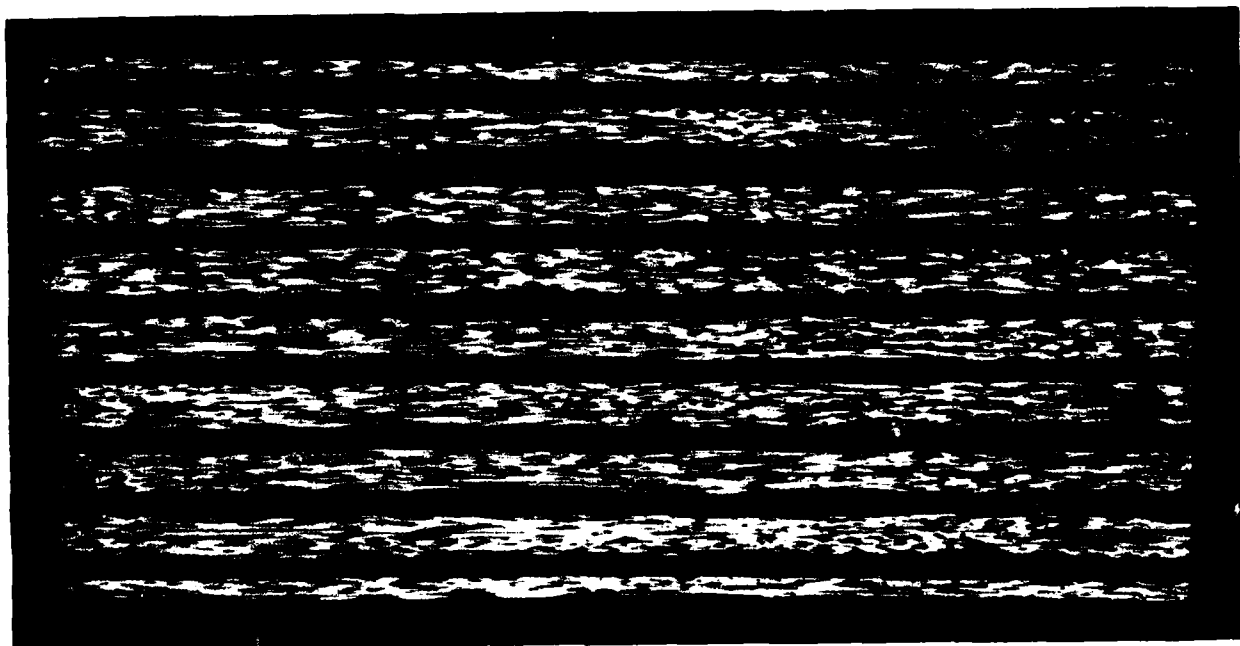
25X

LOCATION: 0.95 IN. DAMAGE LENGTH: 0.957



E30-7-1

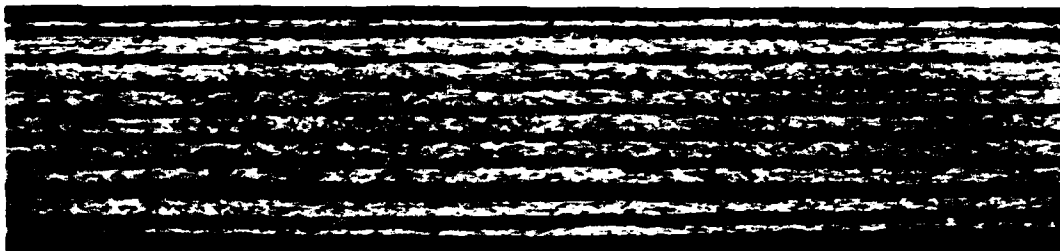
10X



E30-7-2

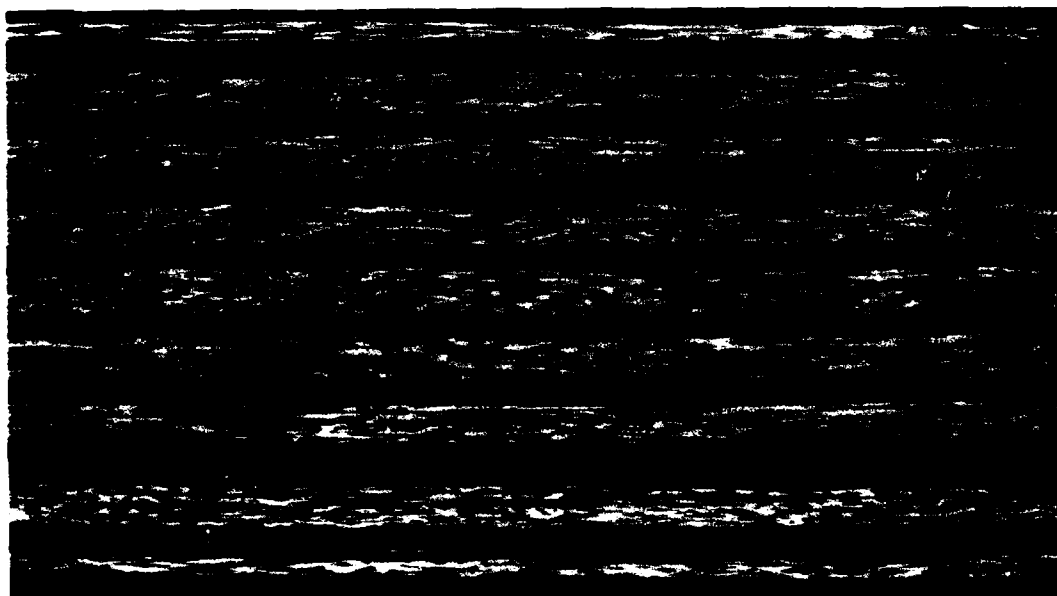
25X

LOCATION: 1.05 IN. DAMAGE LENGTH: 1.192



E30-8-1

10X



E30-8-2

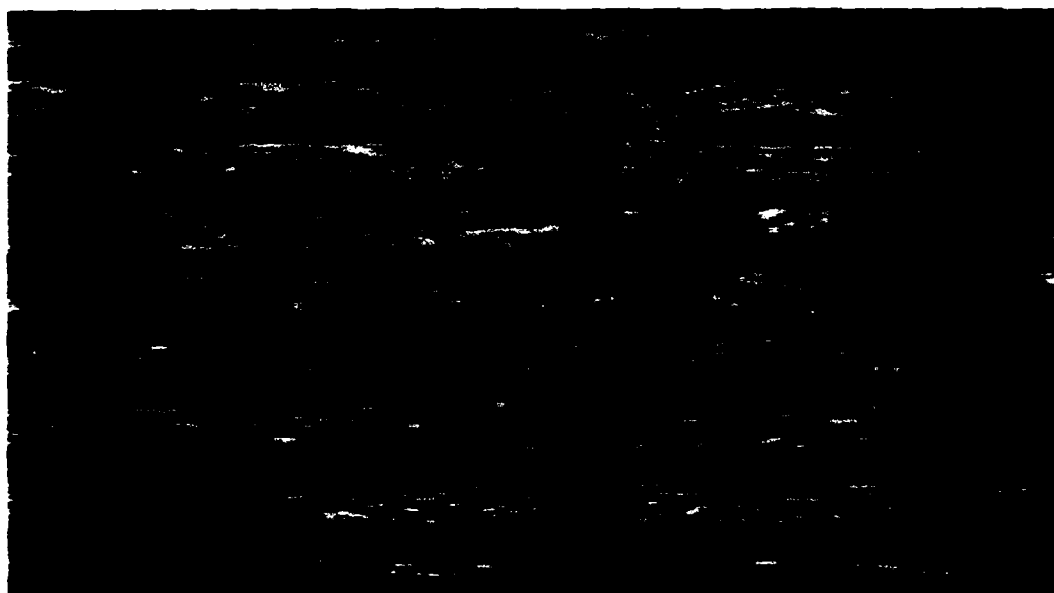
25X

LOCATION: 1.15 IN. DAMAGE LENGTH: 1.138



E30-9-1

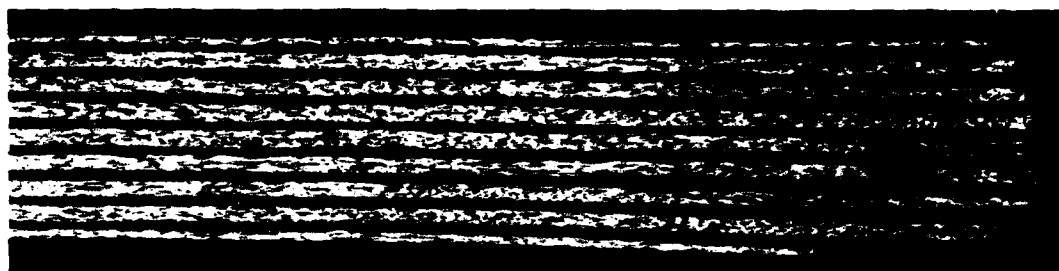
10X



E30-9-2

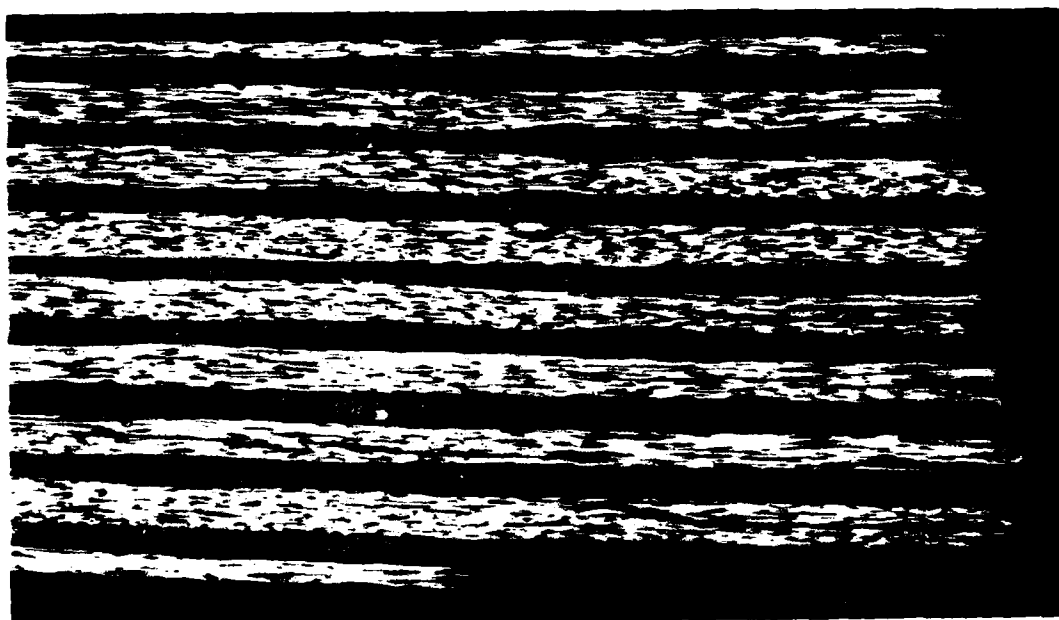
25X

LOCATION: 1.25 IN. DAMAGE LENGTH: 1.259



E30-10-1A

10X



E30-10-1A

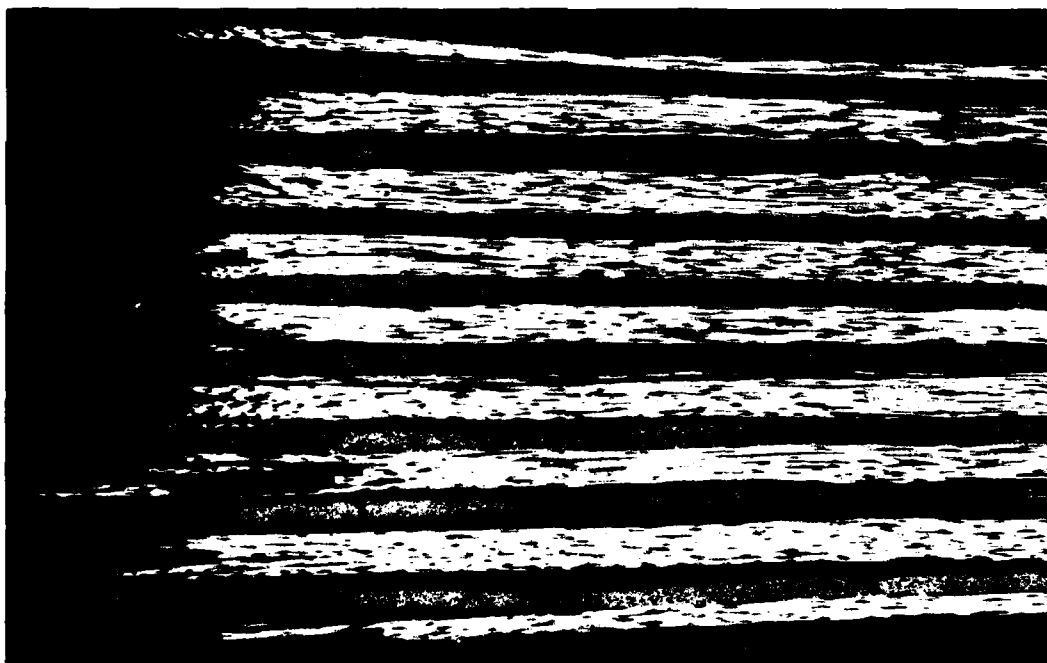
25X

LOCATION: 1.35 in. DAMAGE LENGTH: 1,200



E30-10-1B

10X



E30-10-2B

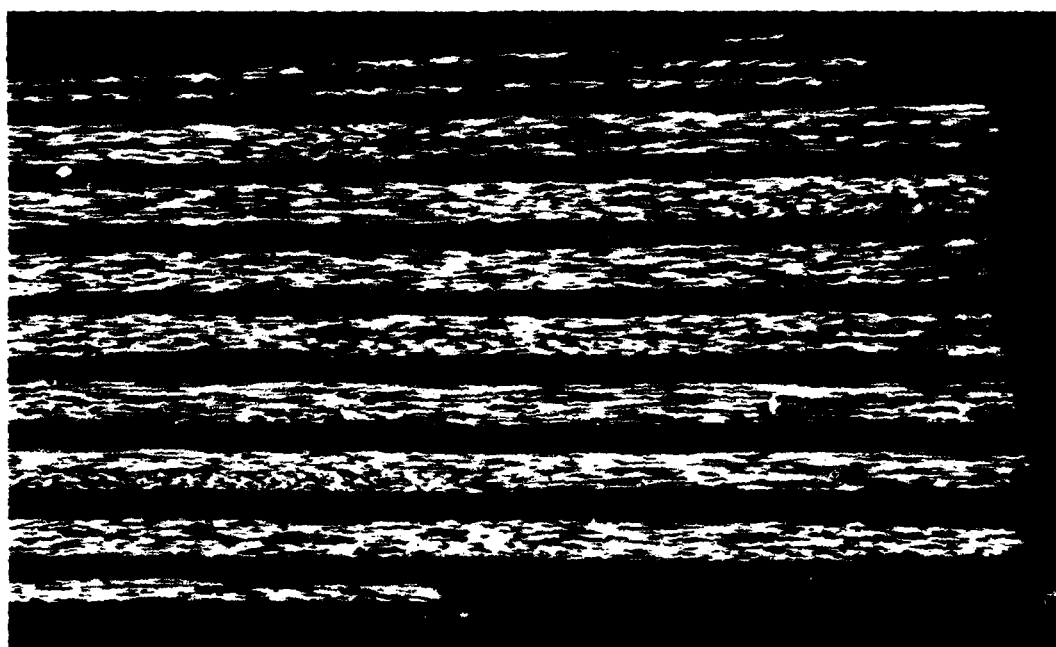
25X

LOCATION: 1.35 IN. DAMAGE LENGTH: 1.200



E30-11-1A

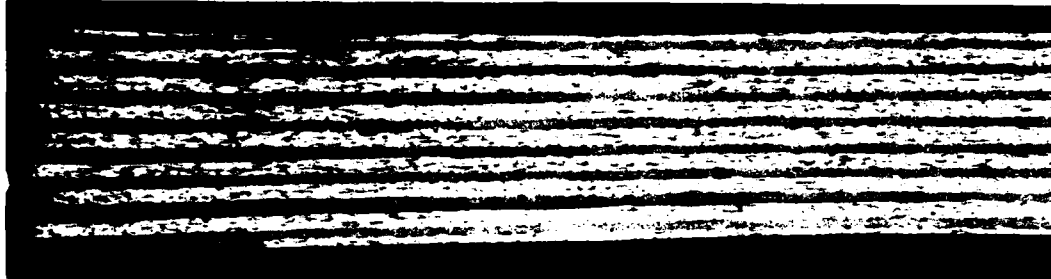
10X



E30-11-2A

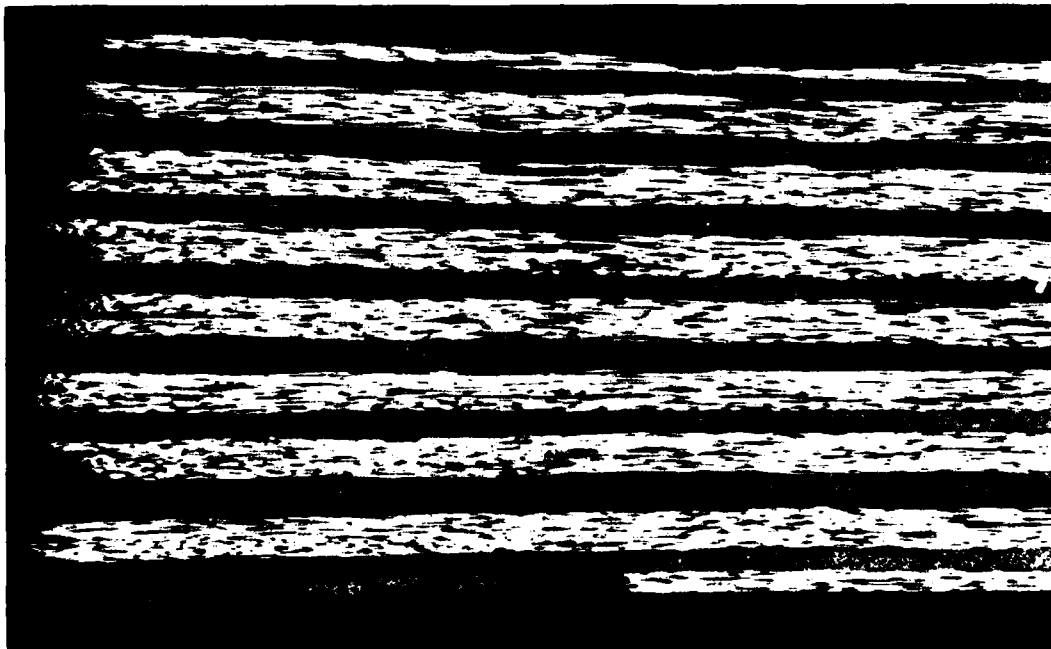
25X

LOCATION: 1.45 in. DAMAGE LENGTH: 1.277



E30-11-1B

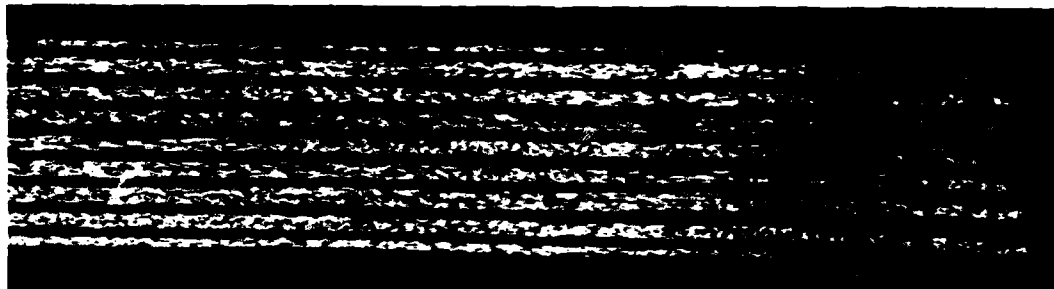
10X



E30-11-2B

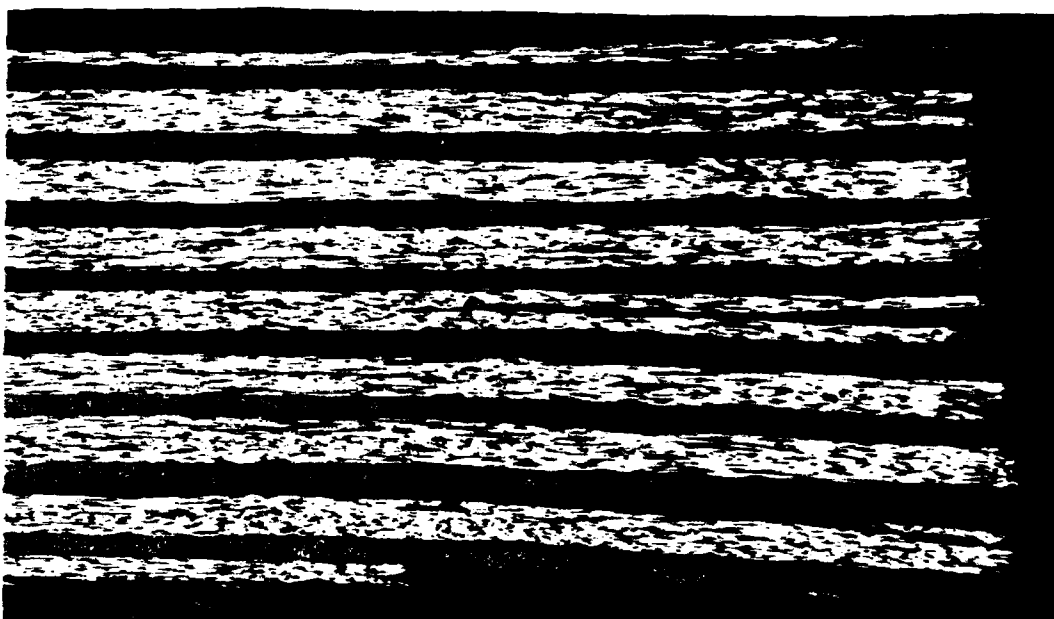
25X

LOCATION: 1.45 IN. DAMAGE LENGTH: 1.277



E30-12-1A

10X



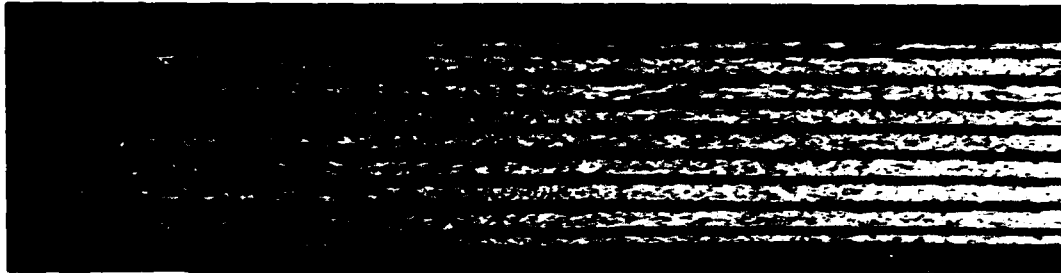
E30-12-1A

25X



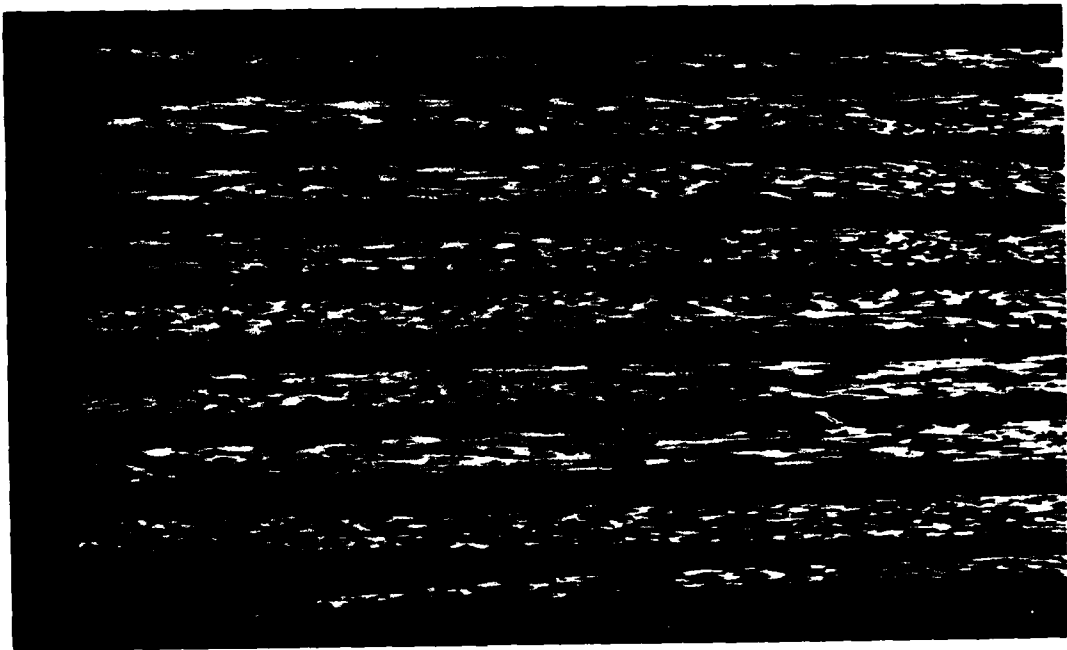
B-SCAN AT CENTER

LOCATION: 1.55 in. DAMAGE LENGTH: 1.317



E30-12-2B

10X



E30-12-2B

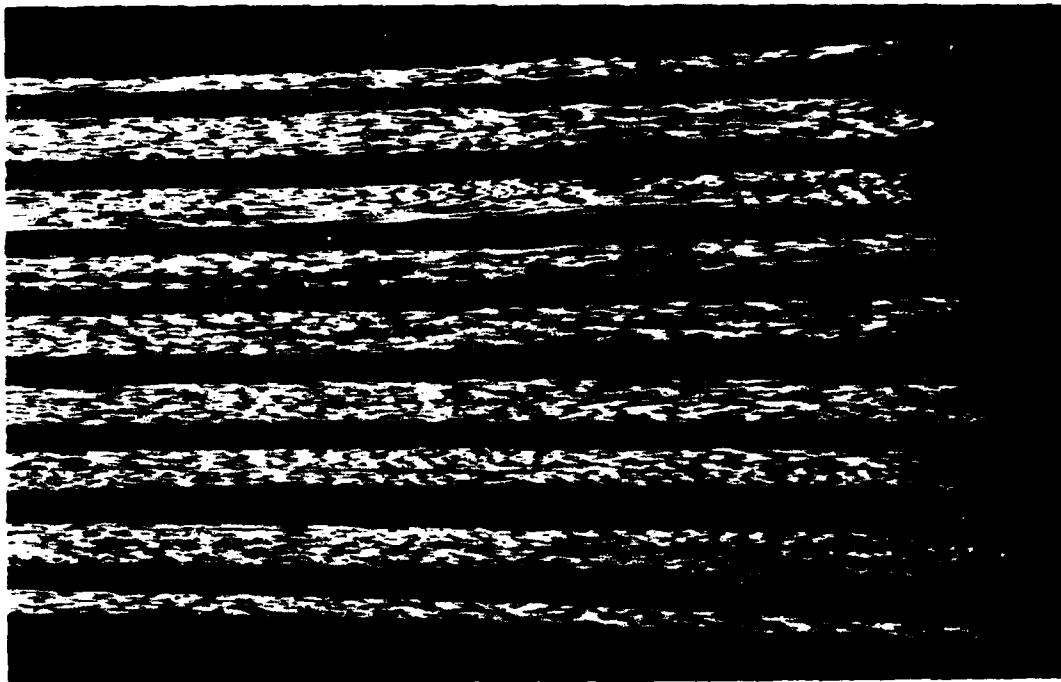
25X

LOCATION: 1.55 in. DAMAGE LENGTH: 1.317



E30-13-1A

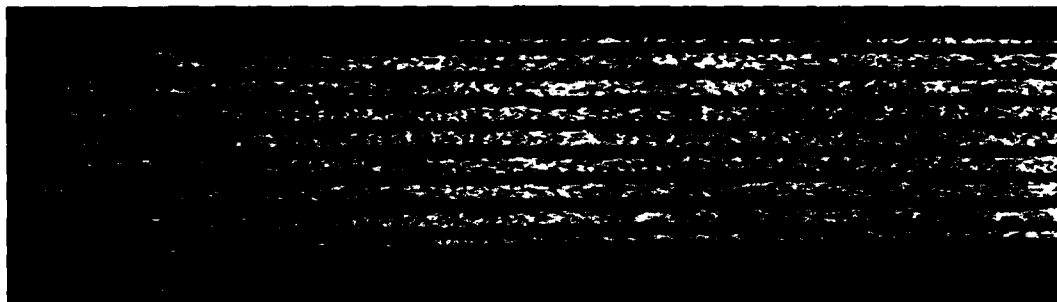
10X



E30-13-1B

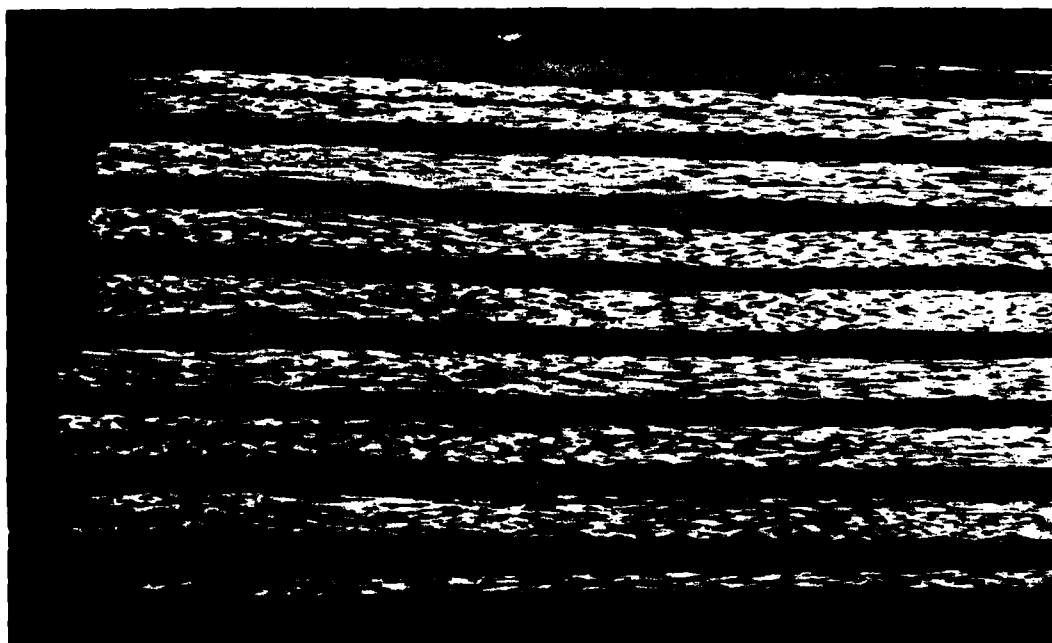
25X

LOCATION: 1.65 IN. DAMAGE LENGTH: 1.285



E30-13-1B

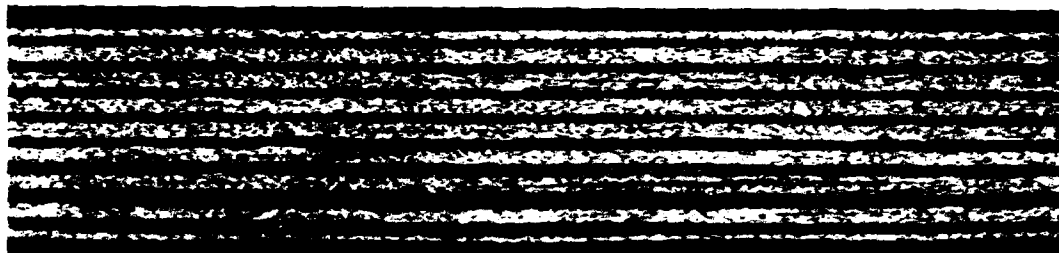
10X



E30-13-2B

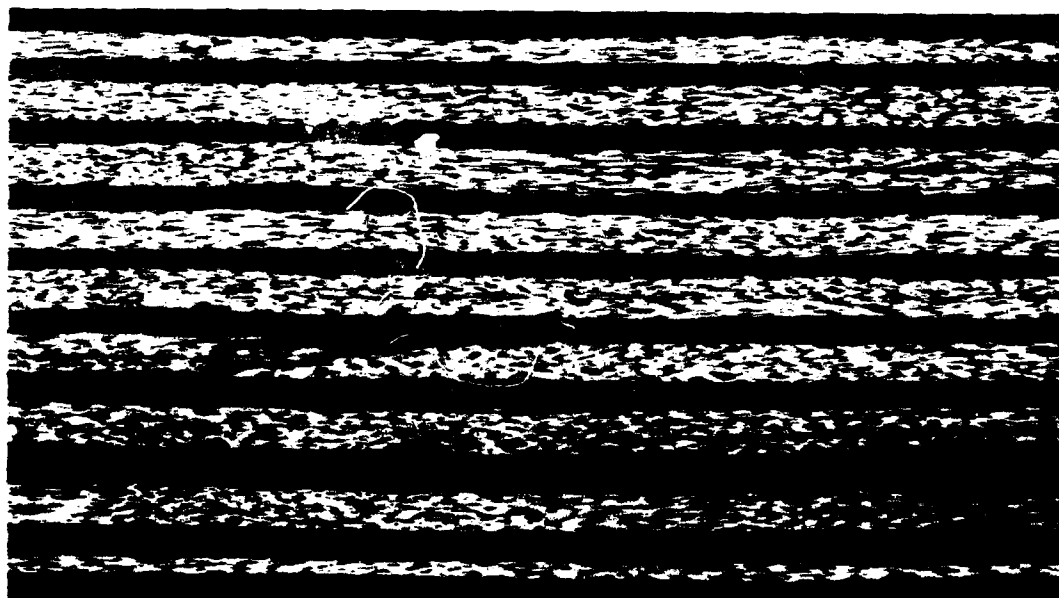
25X

LOCATION: 1.65 IN. DAMAGE LENGTH: 1.285



E30-14-1

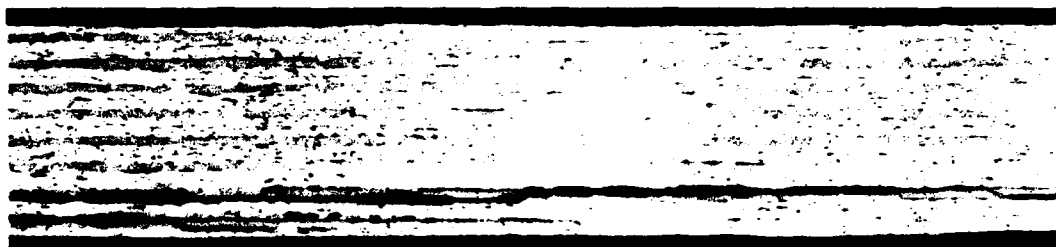
10X



E30-14-2

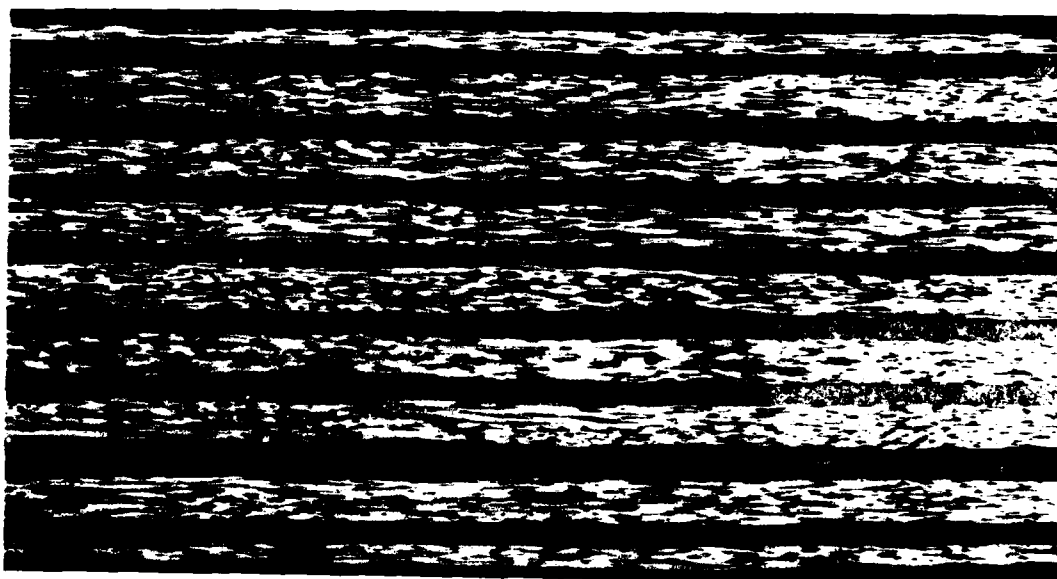
25X

LOCATION: 1.75 IN. DAMAGE LENGTH: 1.260



E30-15-1

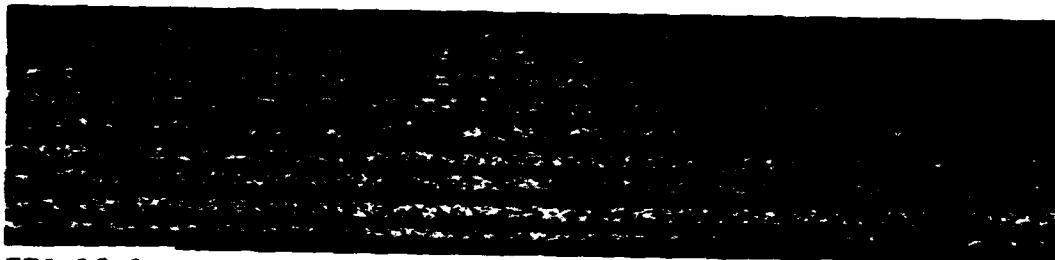
10X



E30-15-2

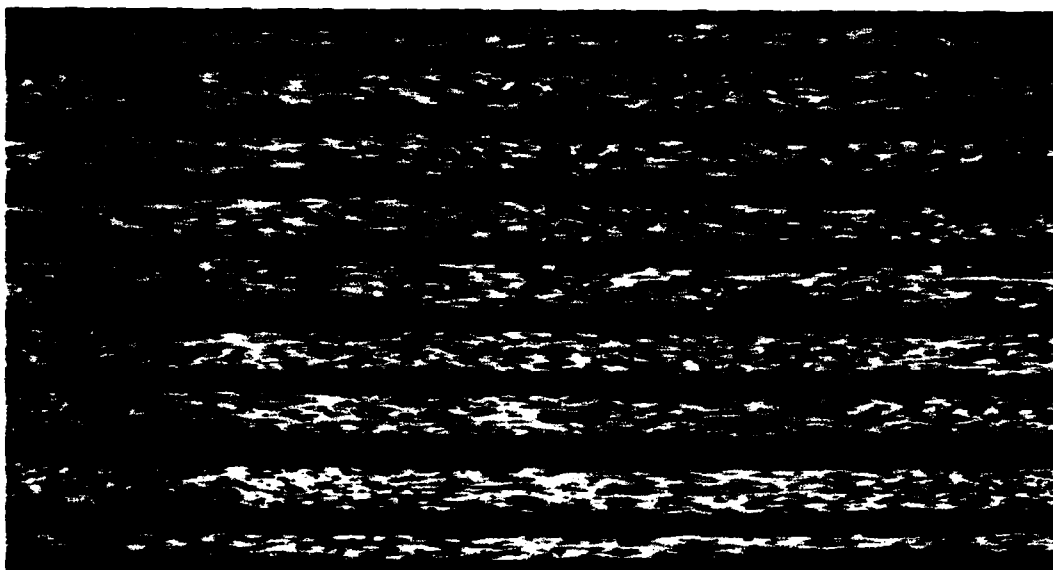
25X

LOCATION: 1.85 in. DAMAGE LENGTH: 1.297



E30-16-1

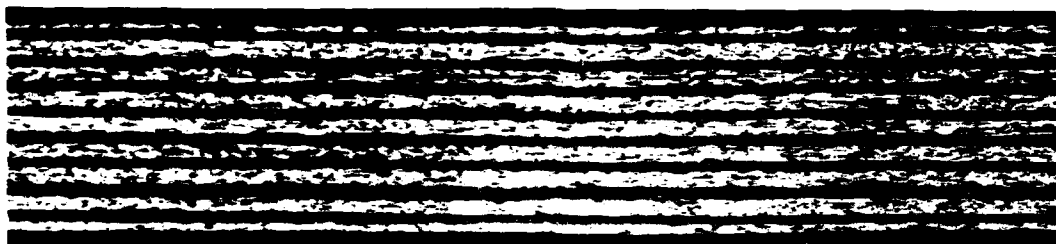
10X



E30-16-2

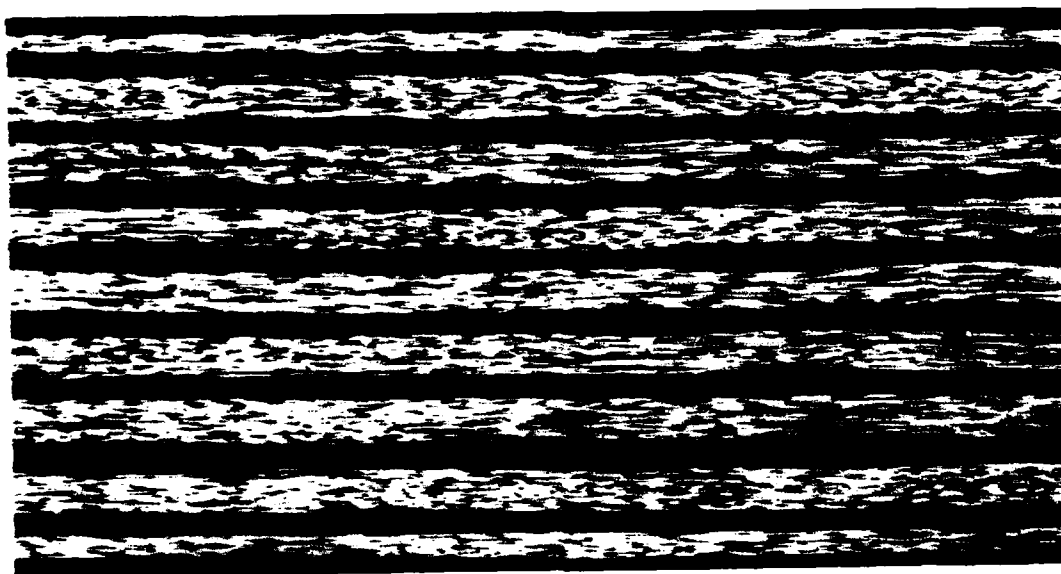
25X

LOCATION: 1.95 IN. DAMAGE LENGTH: 1.205



E30-17-1

10X



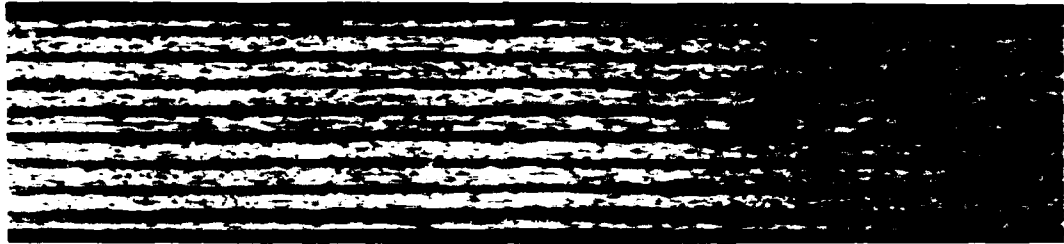
E30-17-2

25X



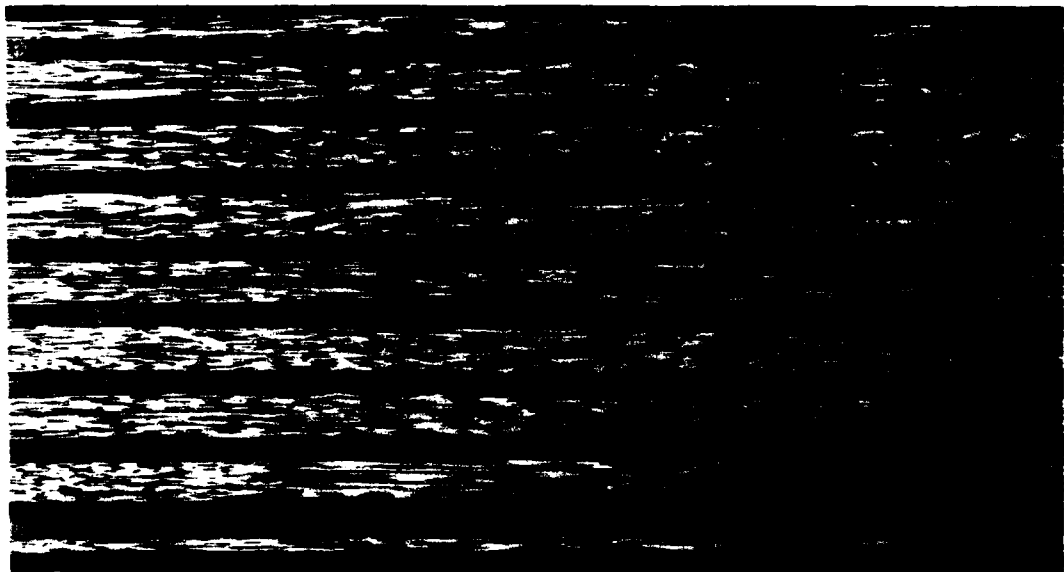
B-SCAN AT 2.08 IN.

LOCATION: 2.05 IN. DAMAGE LENGTH: 1.130



E30-18-1

10X



E30-18-2

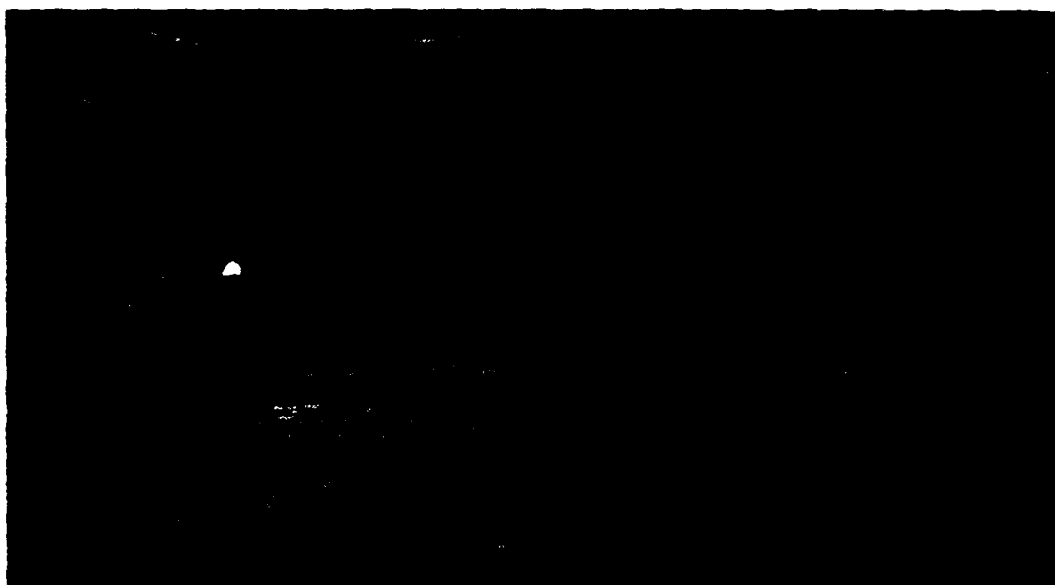
25X

LOCATION: 2.15 IN. DAMAGE LENGTH: 1.112



E30-19-1

10X

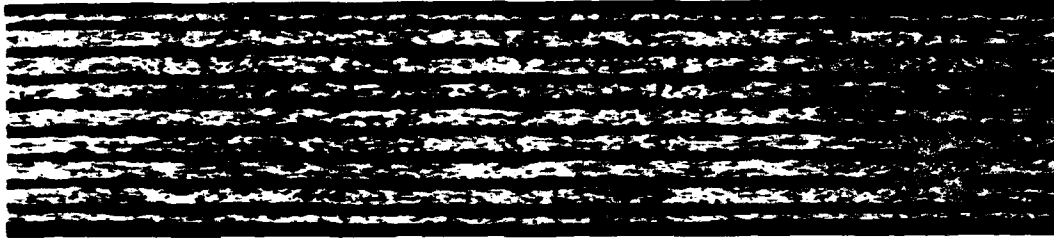


E30-19-2

25X

LOCATION: 2.25 IN. DAMAGE LENGTH: 0.907

G71



E30-20-1

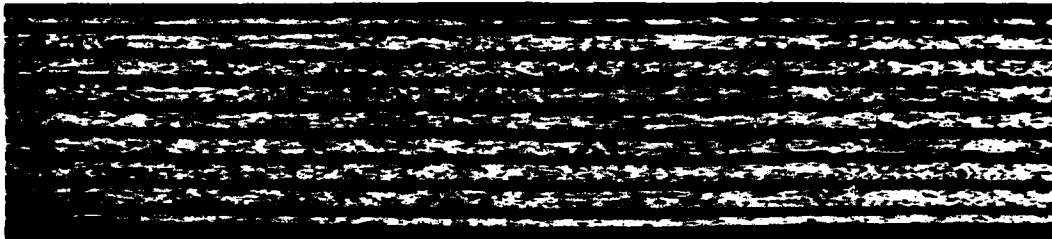
10X



E30-20-2

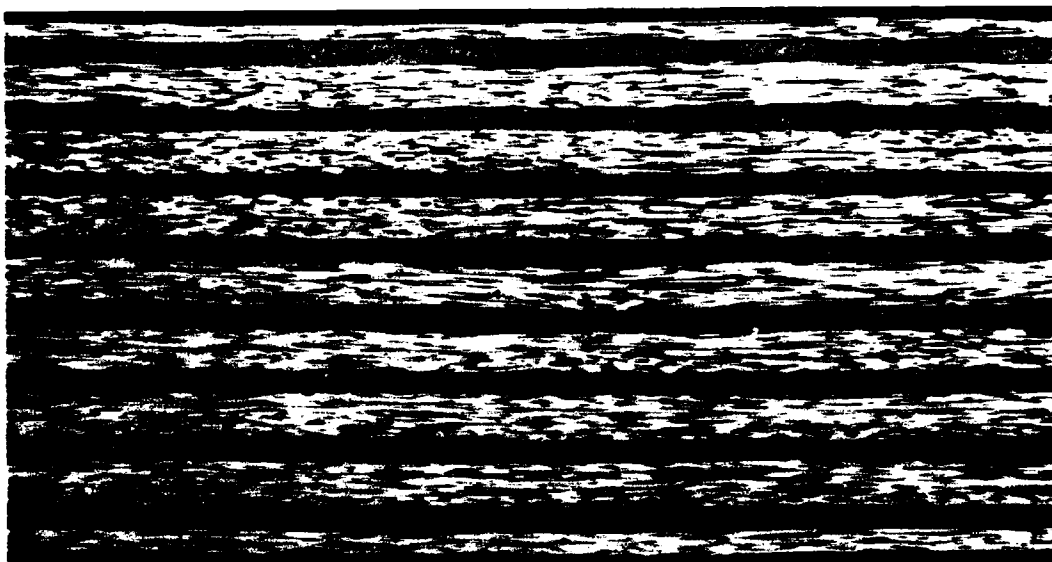
25X

LOCATION: 2.35 IN. DAMAGE LENGTH: 0.571



E30-21-1

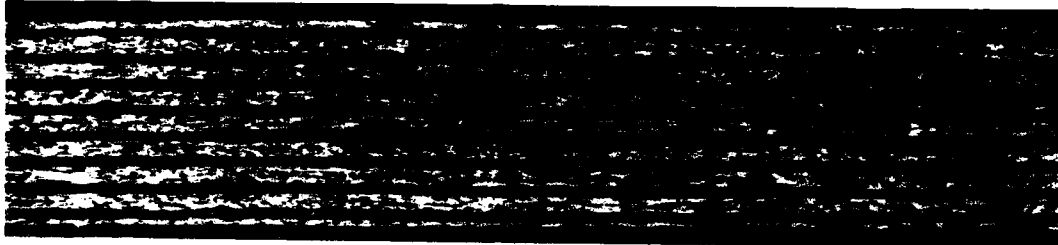
10X



E30-21-2

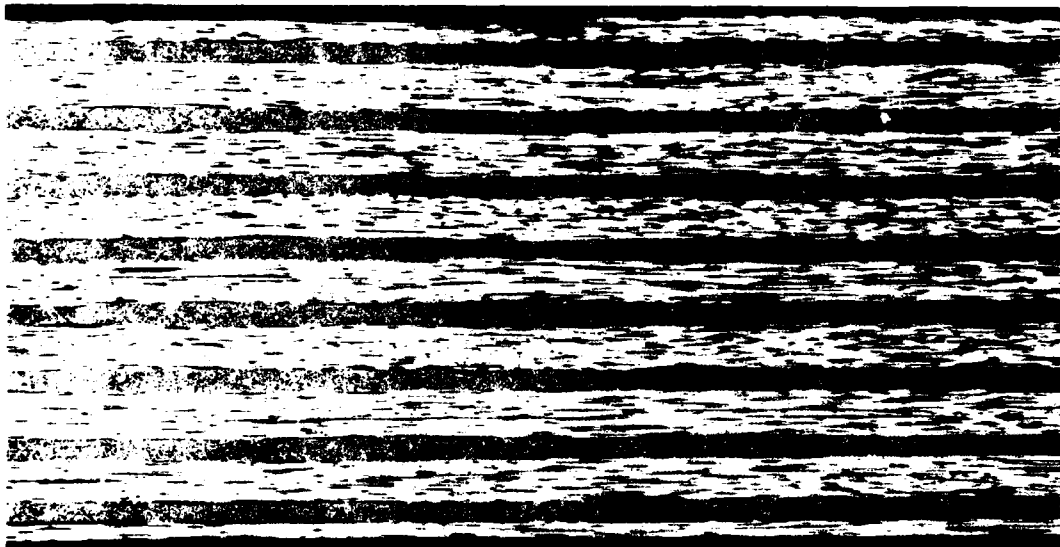
25X

LOCATION: 2.45 IN. DAMAGE LENGTH: 0.453



E30-22-1

10X

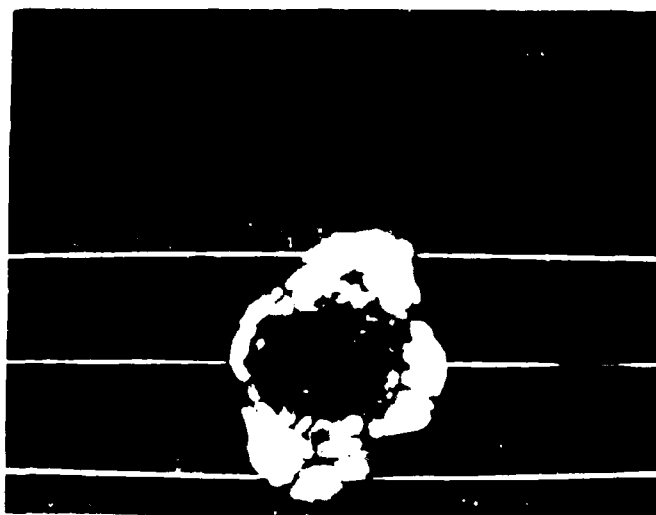


E30-22-1

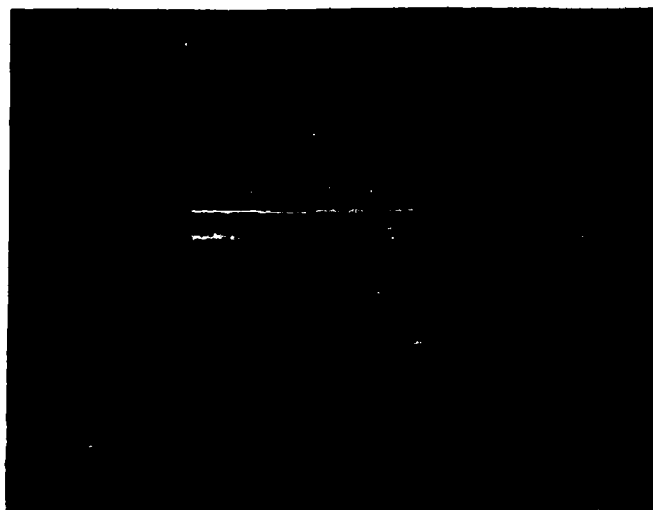
25X

LOCATION: 2.55 IN. DAMAGE LENGTH: NO DAMAGE

G74

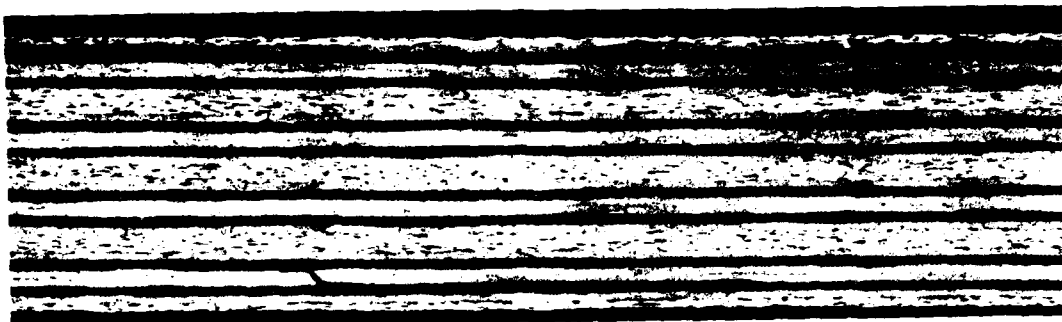


C-SCAN



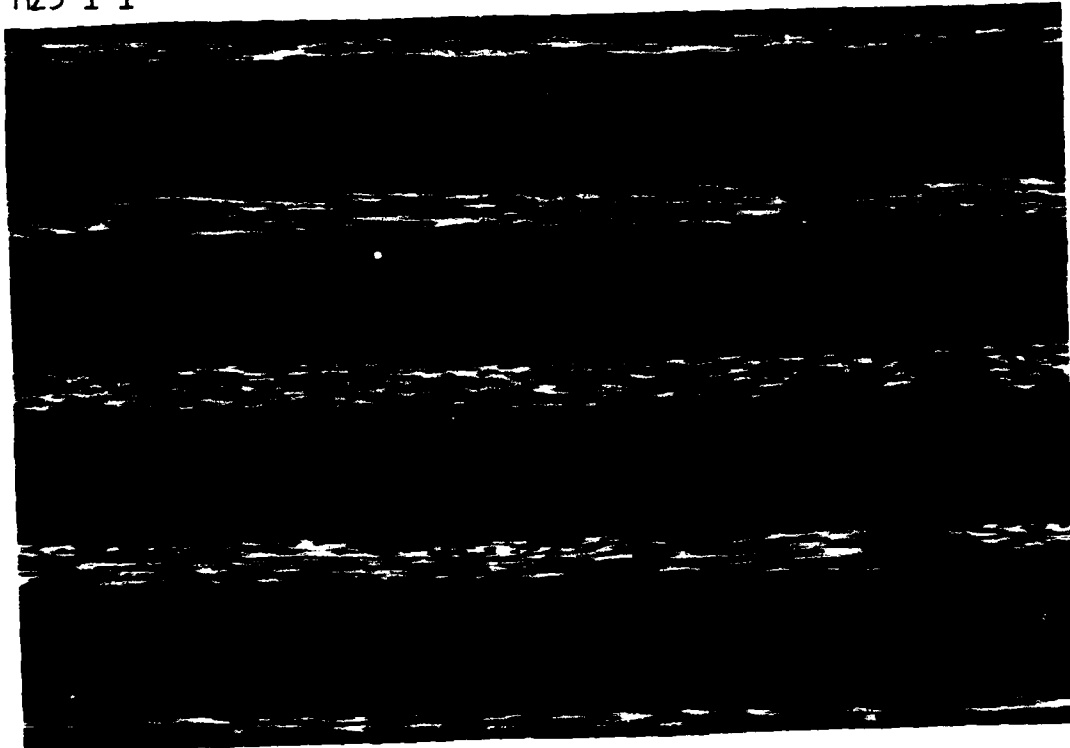
CUMULATIVE B-SCAN

32-PLY SPEC: MC-23 $N_1 = 1,000$ CYCLES



M23-1-1

10x



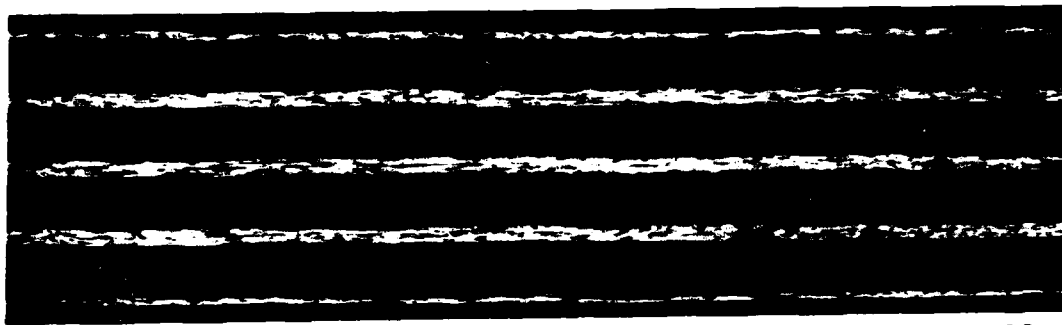
M23-1-2

25x

LOCATION: 1.03 IN. DAMAGE LENGTH: 0.308

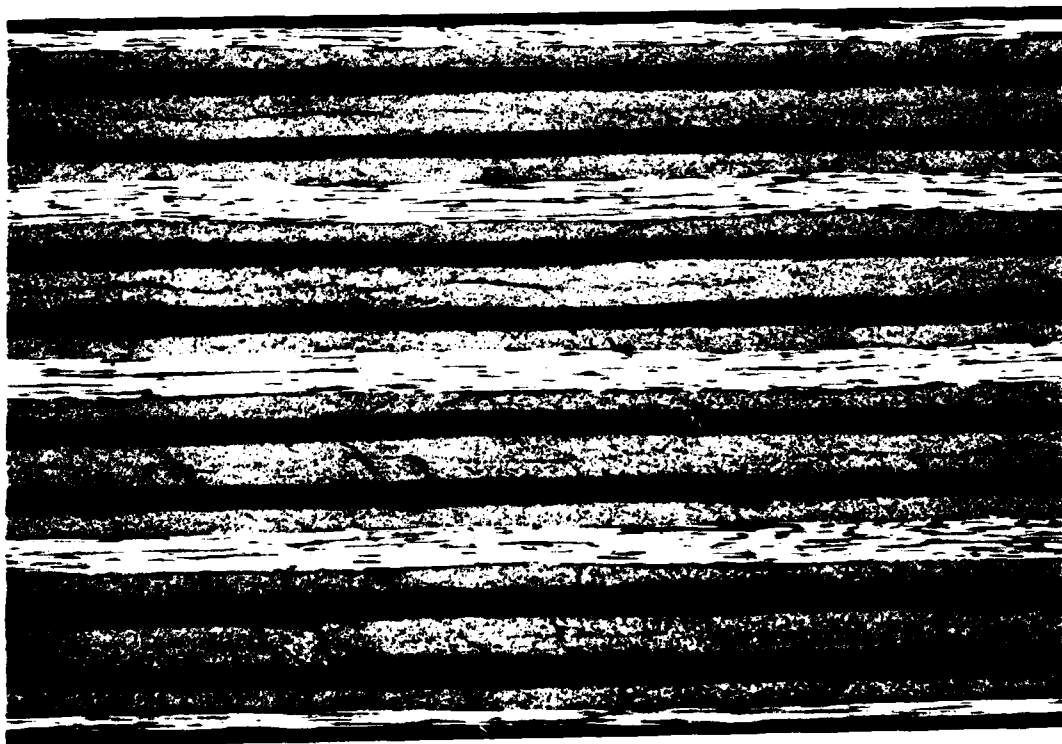


B-SCAN
AT 1.03 IN.



M23-2-1

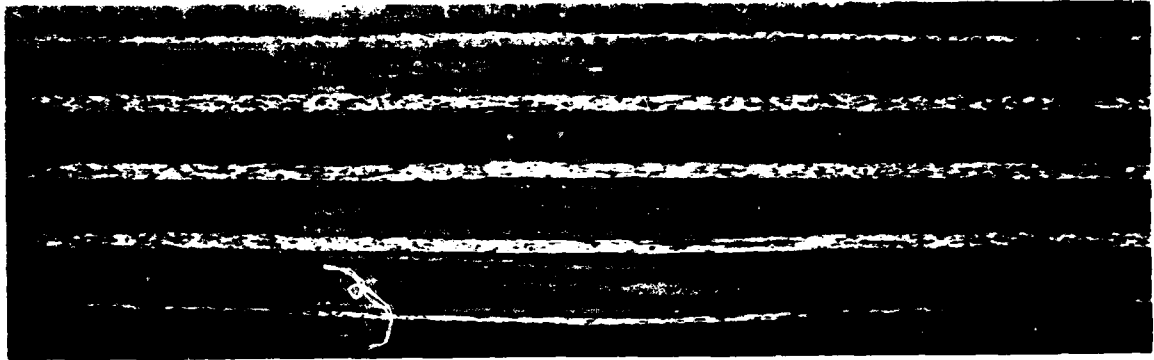
10x



M23-2-2

25x

LOCATION: 1.13 DAMAGE LENGTH 0.479 IN.



M23-3-1

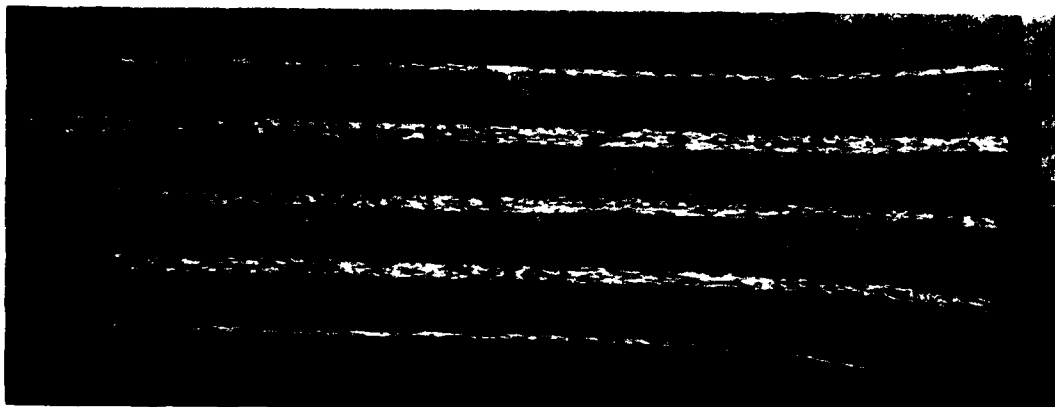
10x



M23-3-2

25x

LOCATION: 1.23 IN. DAMAGE LENGTH: 0.619



M23-4-1A

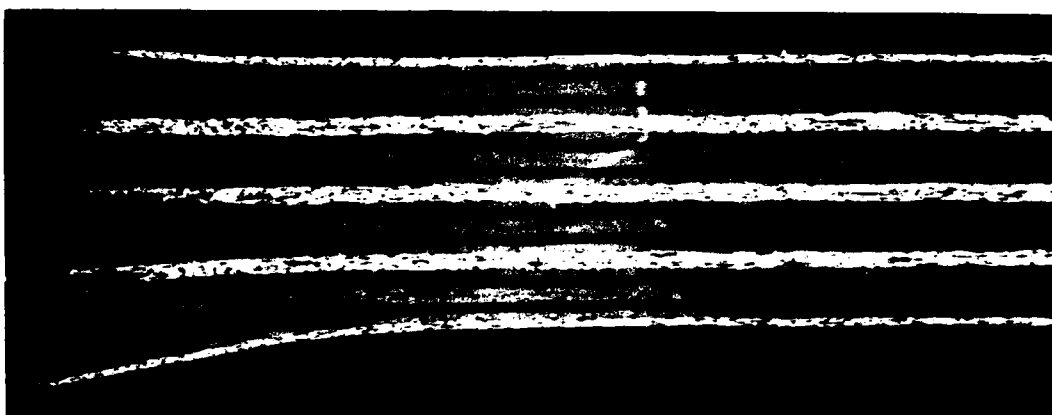
10x



M23-4-2A

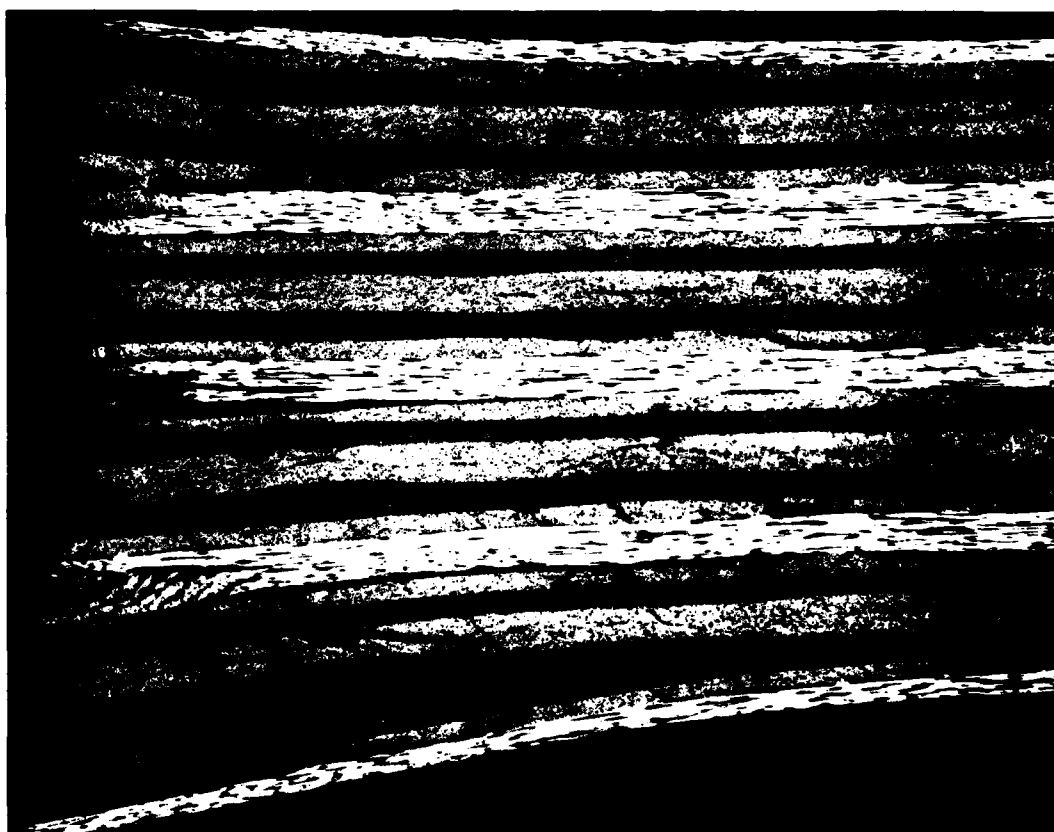
25x

LOCATION: 1.33 in. DAMAGE LENGTH: 0.771



M23-4-1B

10x

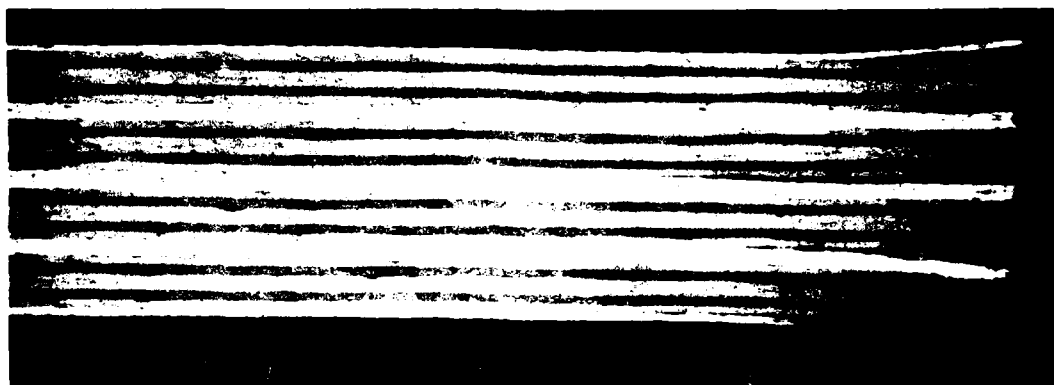


M23-4-2B

25x

LOCATION: 1.33 in. DAMAGE LENGTH: 0.771

G80



M23-5-1A

10x



M23-5-2A

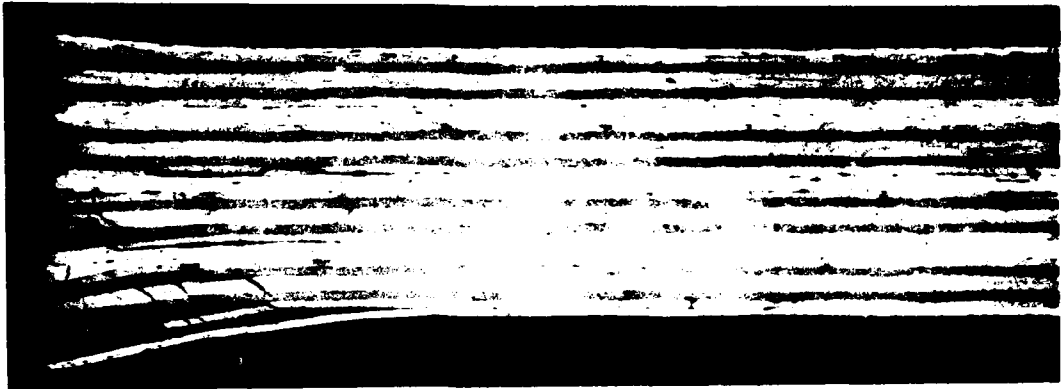
25x

LOCATION: 1.43 IN. DAMAGE LENGTH: 0.781 IN.



B-SCAN
@ 1.5 IN.

G81



M23-5-1B

10x

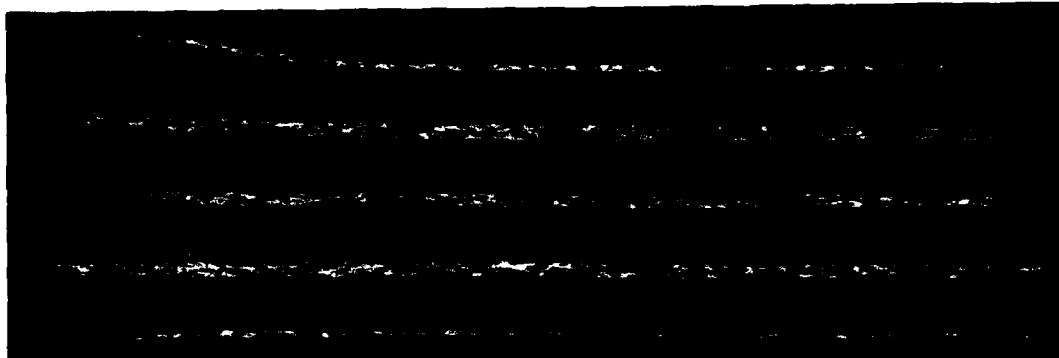


M23-5-2B

25x

LOCATION: 1.43 IN. DAMAGE LENGTH: 0.781

G82



M23-6-1A

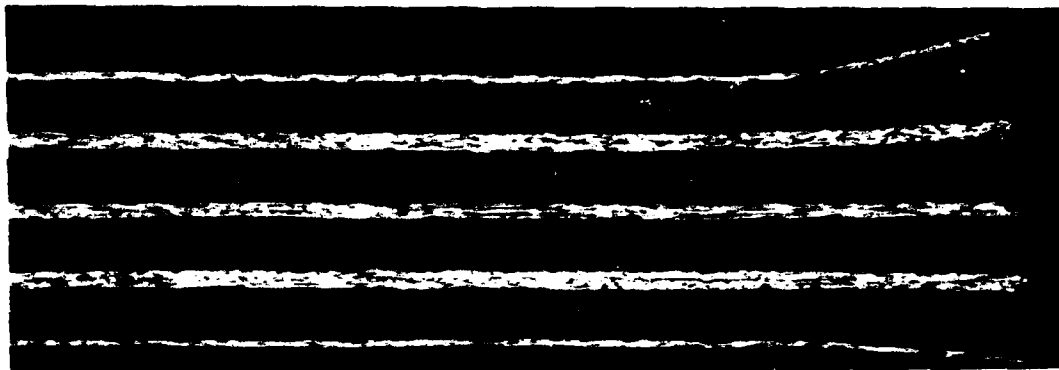
10X



M23-6-2A

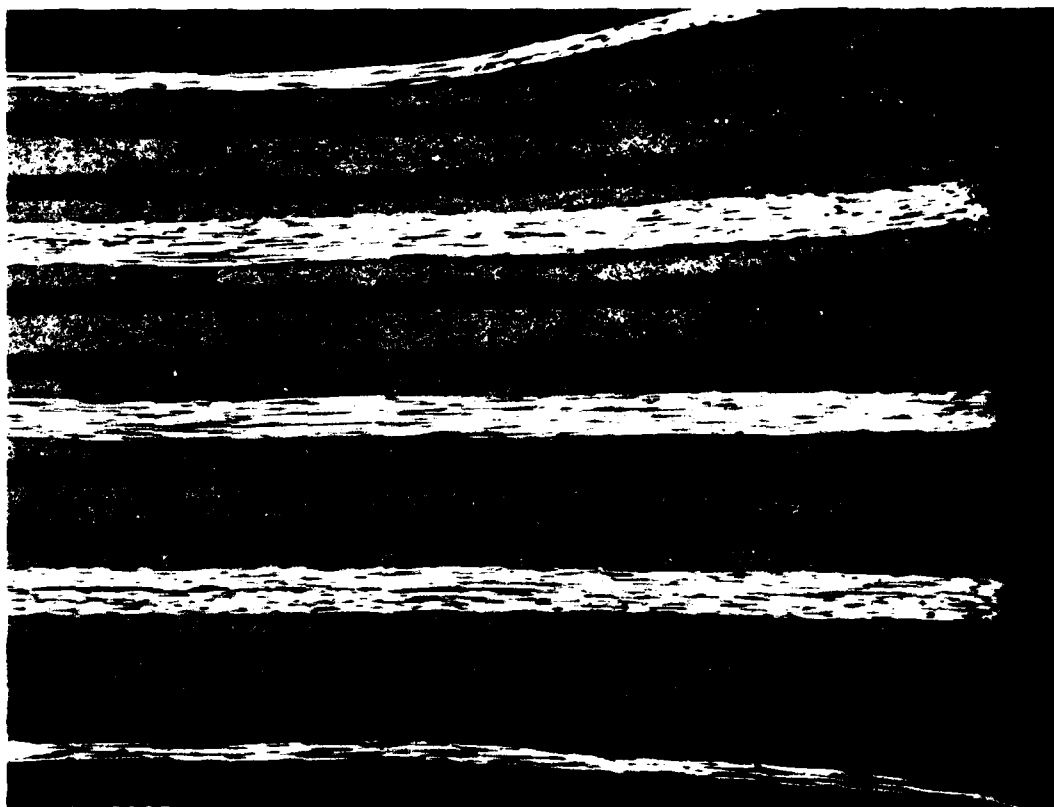
25X

LOCATION: 1.53 in. DAMAGE LENGTH: 0.806"



M-23-6-1B

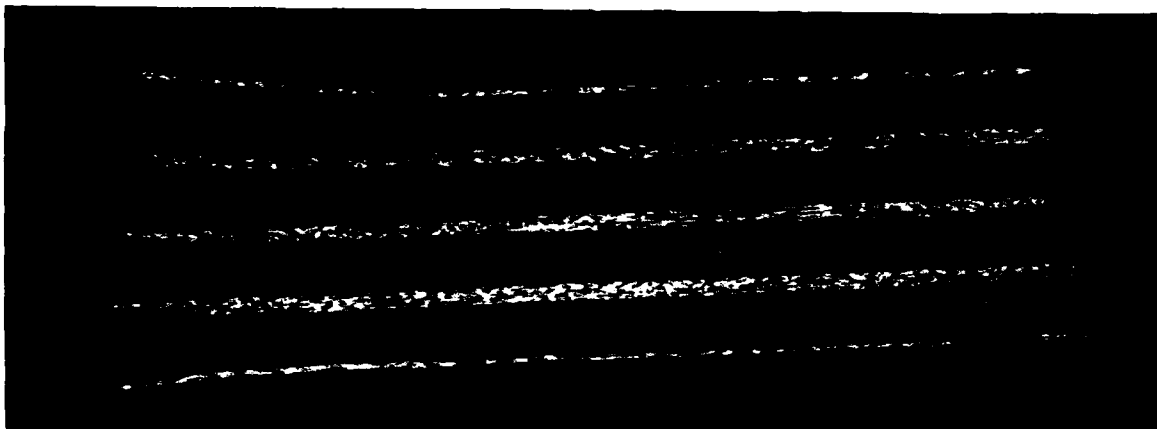
10X



M23-6-2B

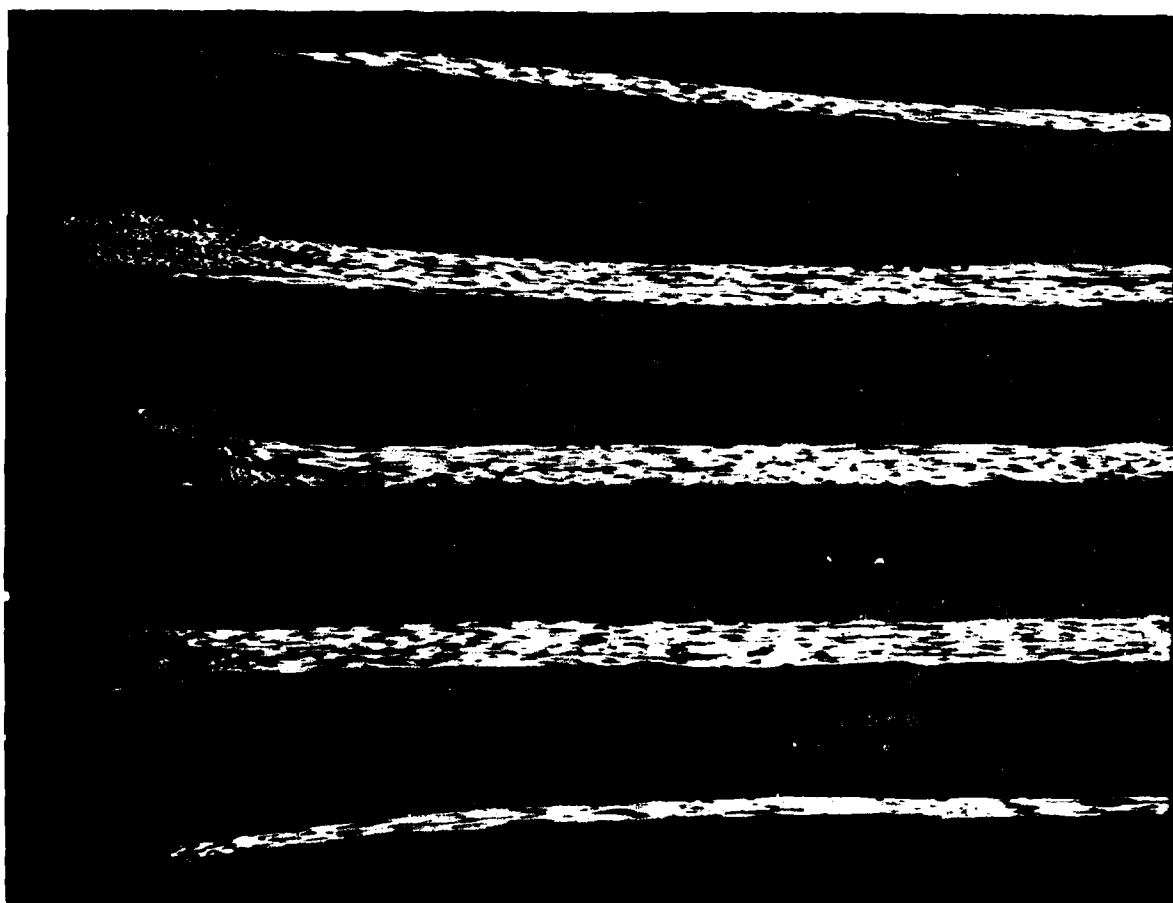
25X

LOCATION: 1.53 in. DAMAGE LENGTH: 0.806



M23-7-1A

10X

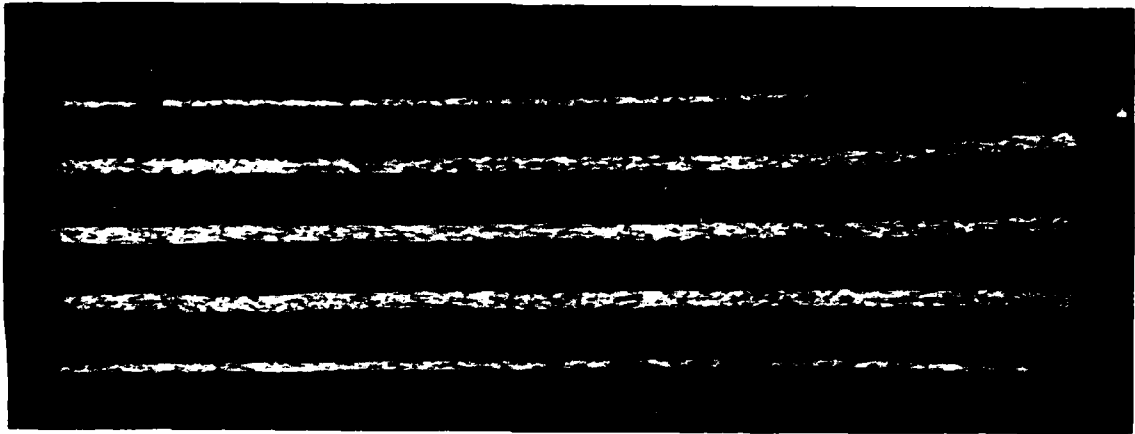


M23-7-2A

25X

LOCATION: 1.63 IN. DAMAGE LENGTH: 0.750

G85



"23-7-1F

10X



"23-7-2I

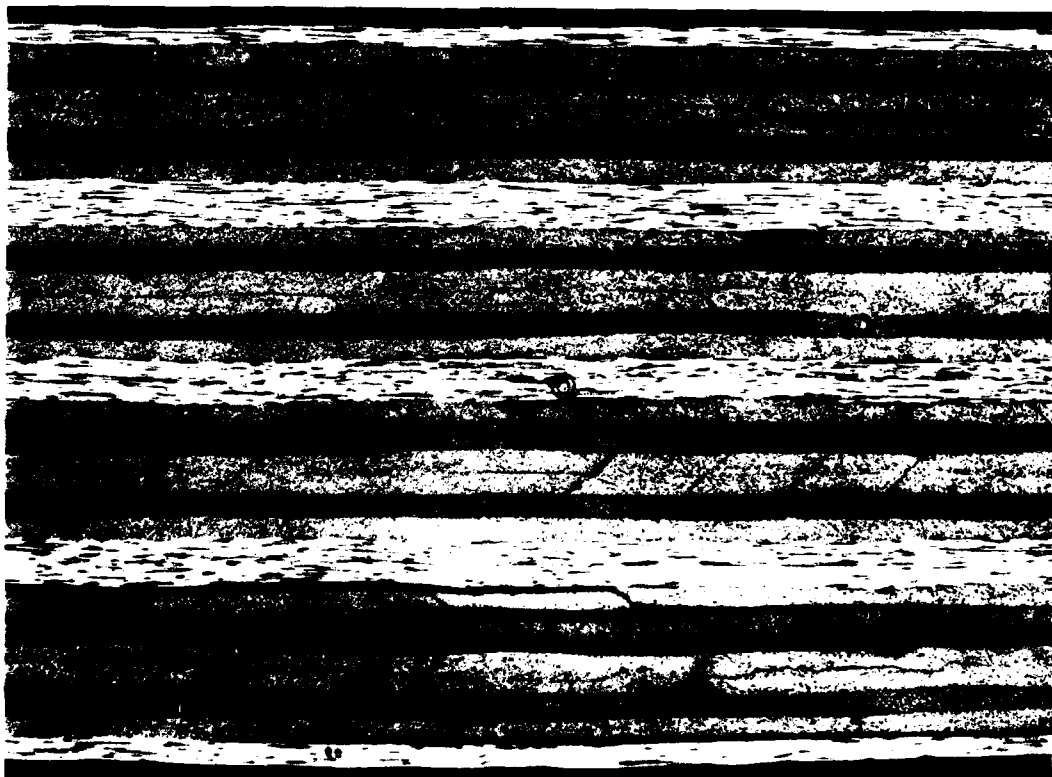
25X

LOCATION: 1.63 IN. DAMAGE LENGTH: 0.750



M23-8-1

10X

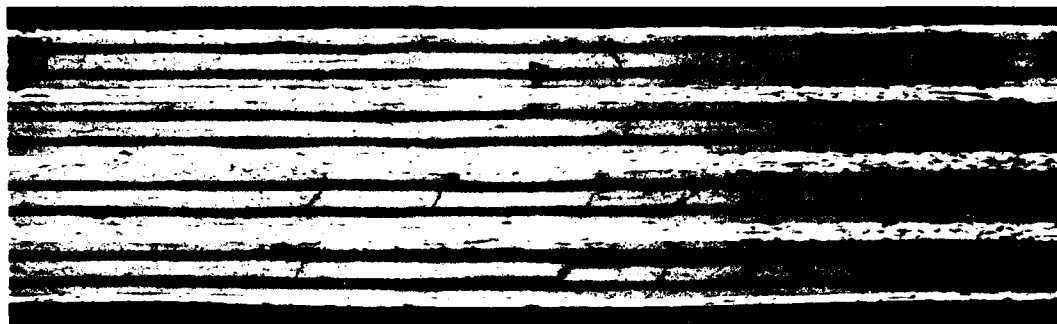


M23-8-2

25 X

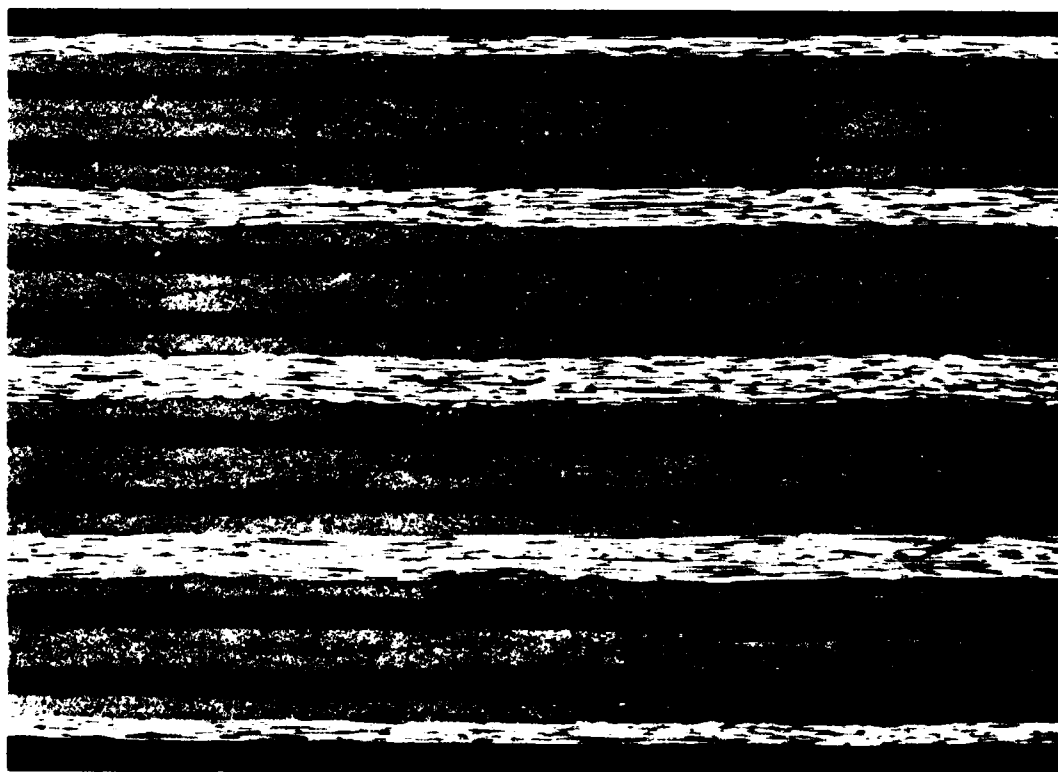
LOCATION: 1.73 IN. DAMAGE LENGTH: 0.670

G87



M23-9-1

10X



M23-9-2

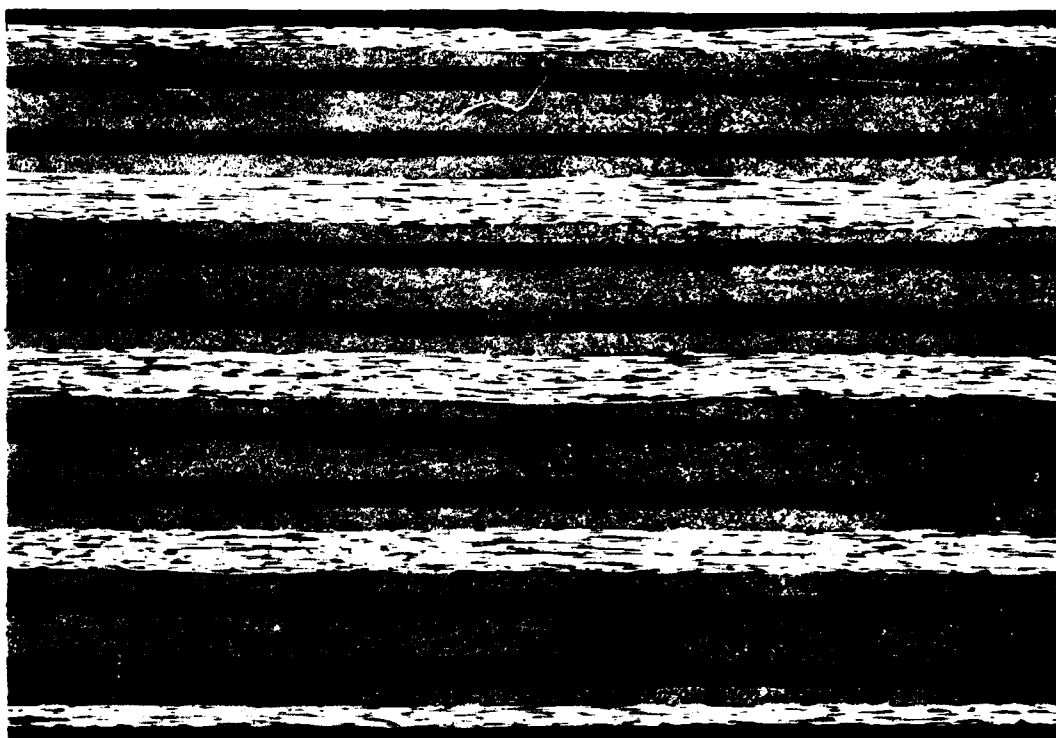
25X

LOCATION: 1.83 IN. DAMAGE LENGTH: 0.586



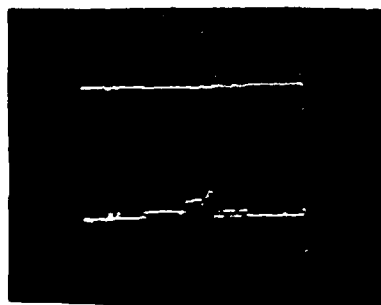
M23-10-1

10X



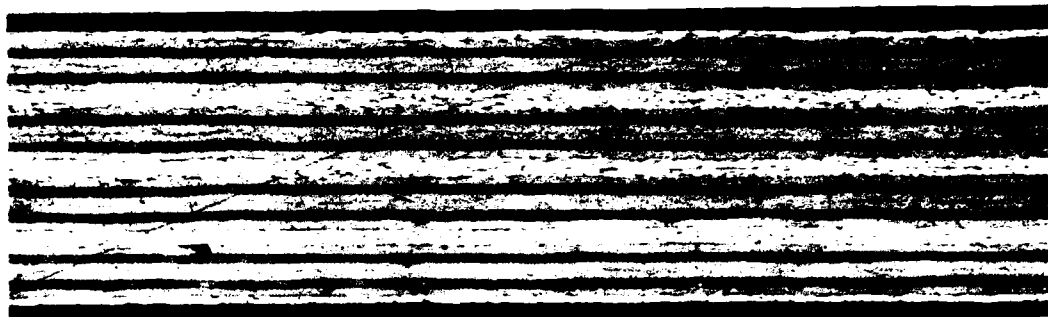
MC23-10-2

25X



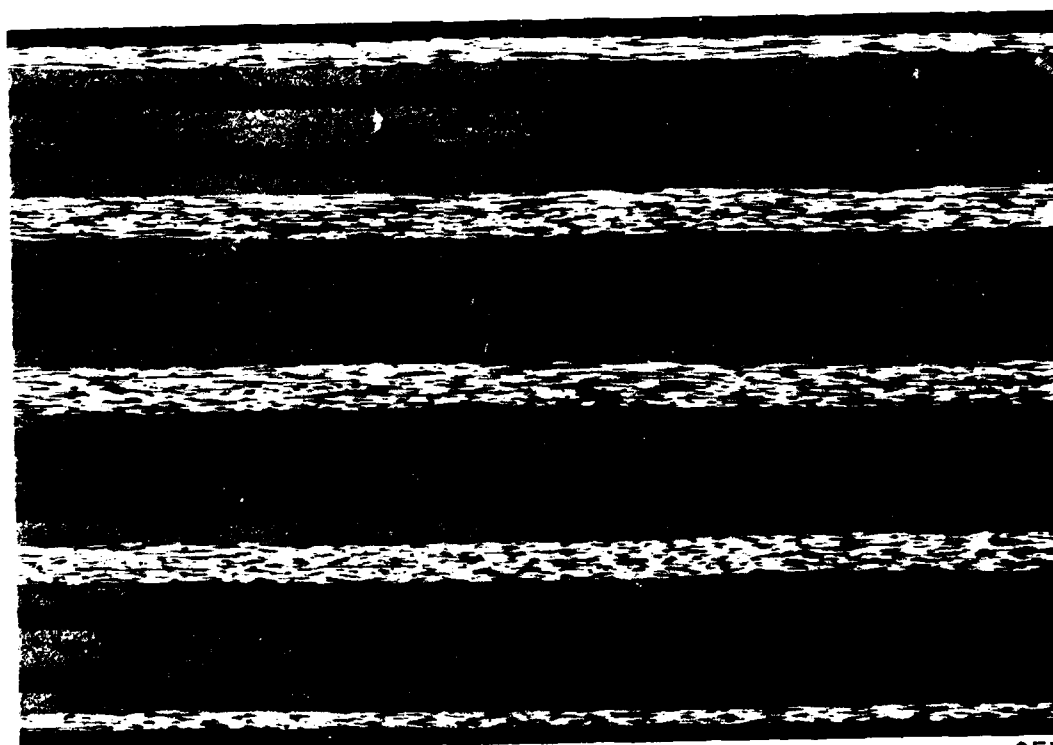
B SCAN AT 1.9

1.07 IN. DAMAGE LENGTH: 0.434



M23-11-1

10X

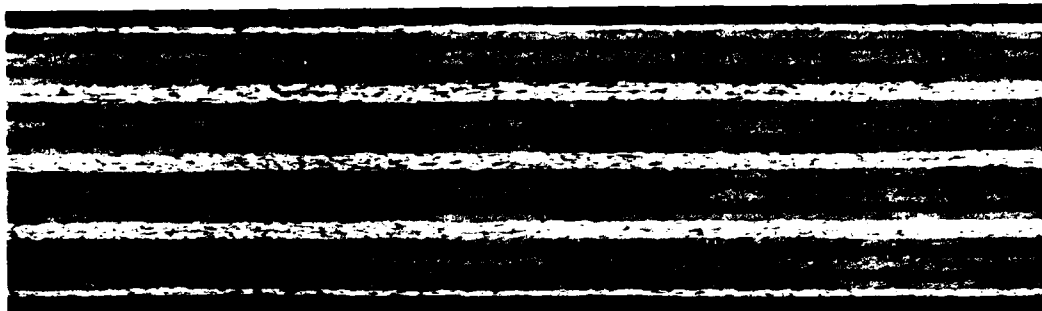


M23-11-2

25X

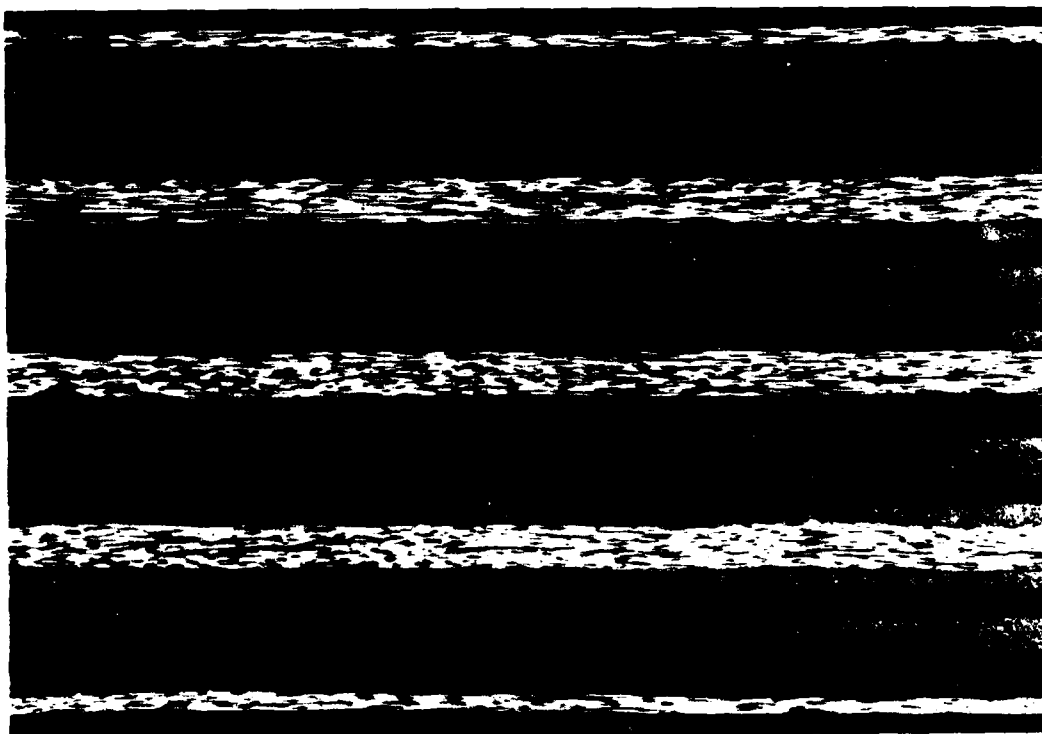
LOCATION: 2.03 IN. DAMAGE LENGTH: 0.188

G90



M23-12-1

10X



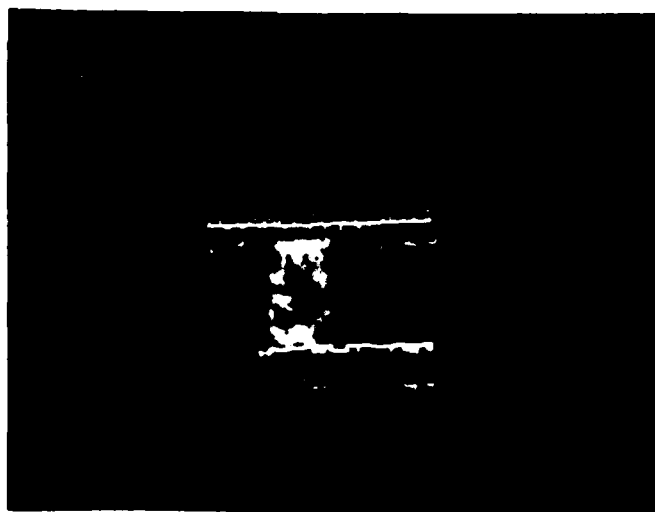
M23-12-2

25X

LOCATION: 2.13 IN. DAMAGE LENGTH: NO DAMAGE



C-SCAN



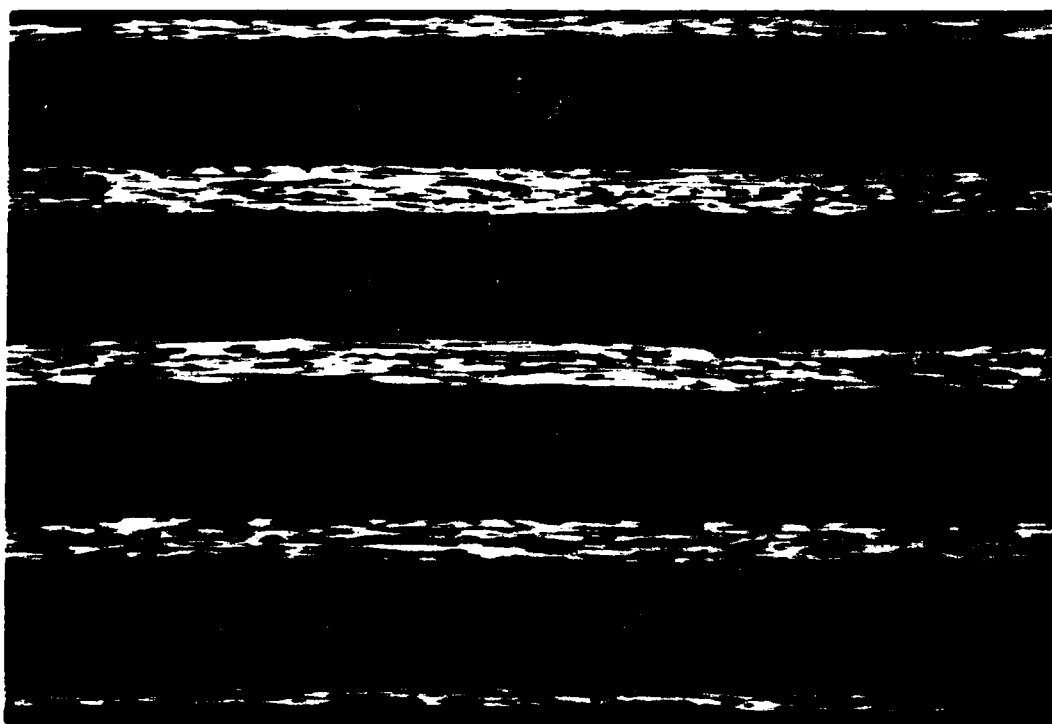
CUMULATIVE B-SCAN

32-PLY SPEC: MC-22 N_2 = 5,000 CYCLES



M22-1-1

10X



M22-1-2

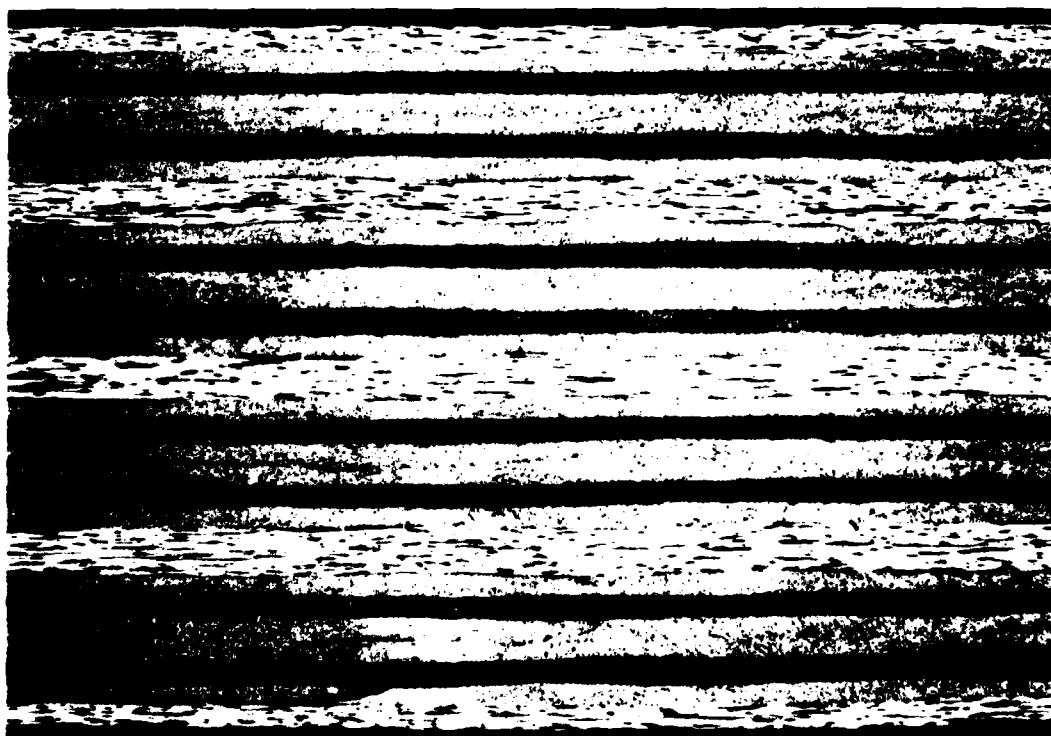
25X

LOCATION: 0.69 in. DAMAGE LENGTH: No Cracks



M22-2-1

10X



M22-2-2

25X

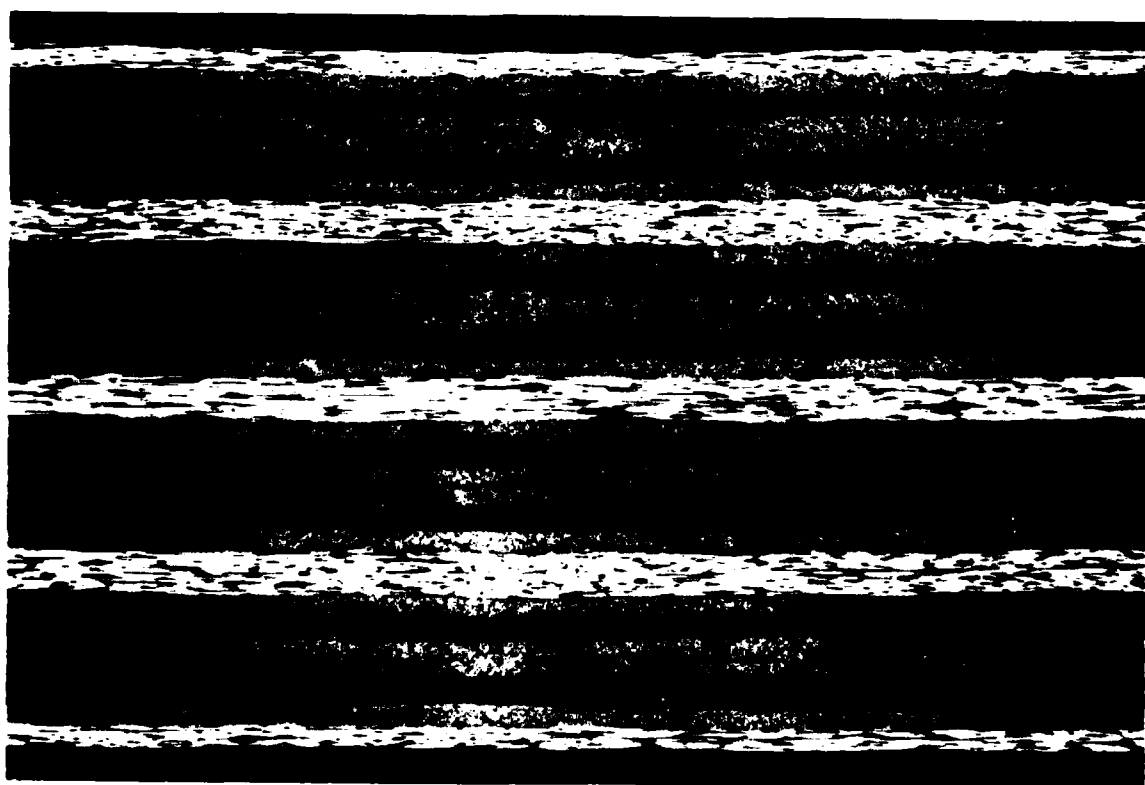
LOCATION: 0.79 IN. DAMAGE LENGTH: 0.318

G94



M22-3-1

10X



M22-3-2

25X

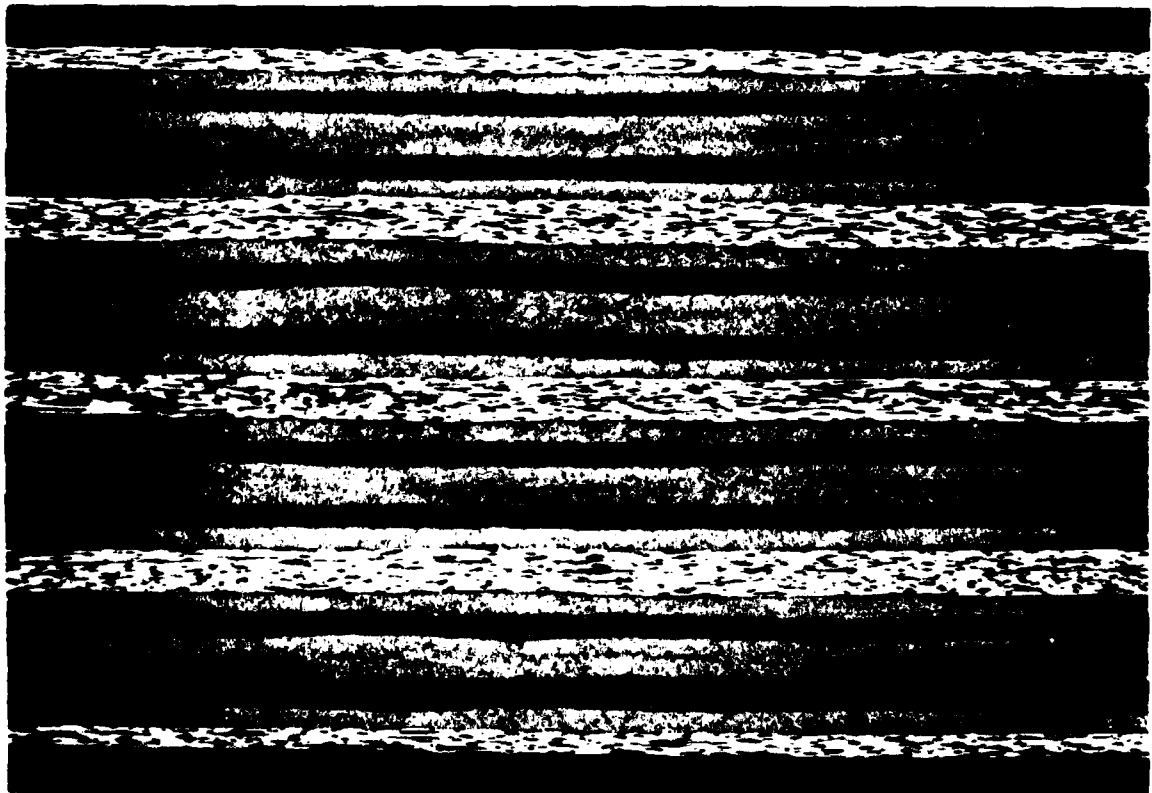
LOCATION: 0.89 IN. DAMAGE LENGTH: 0.419

G95



M22-4-1

10X



M22-4-2

25X

LOCATION: 0.99 IN. DAMAGE LENGTH: 0.620

G96



M22-5-1

10X



M22-5-2

25X

LOCATION: 1.09 IN. DAMAGE LENGTH: 0.836

G97



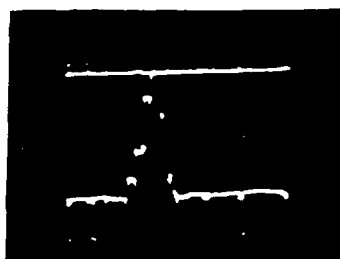
M22-6-1

10X



M22-6-2

25X



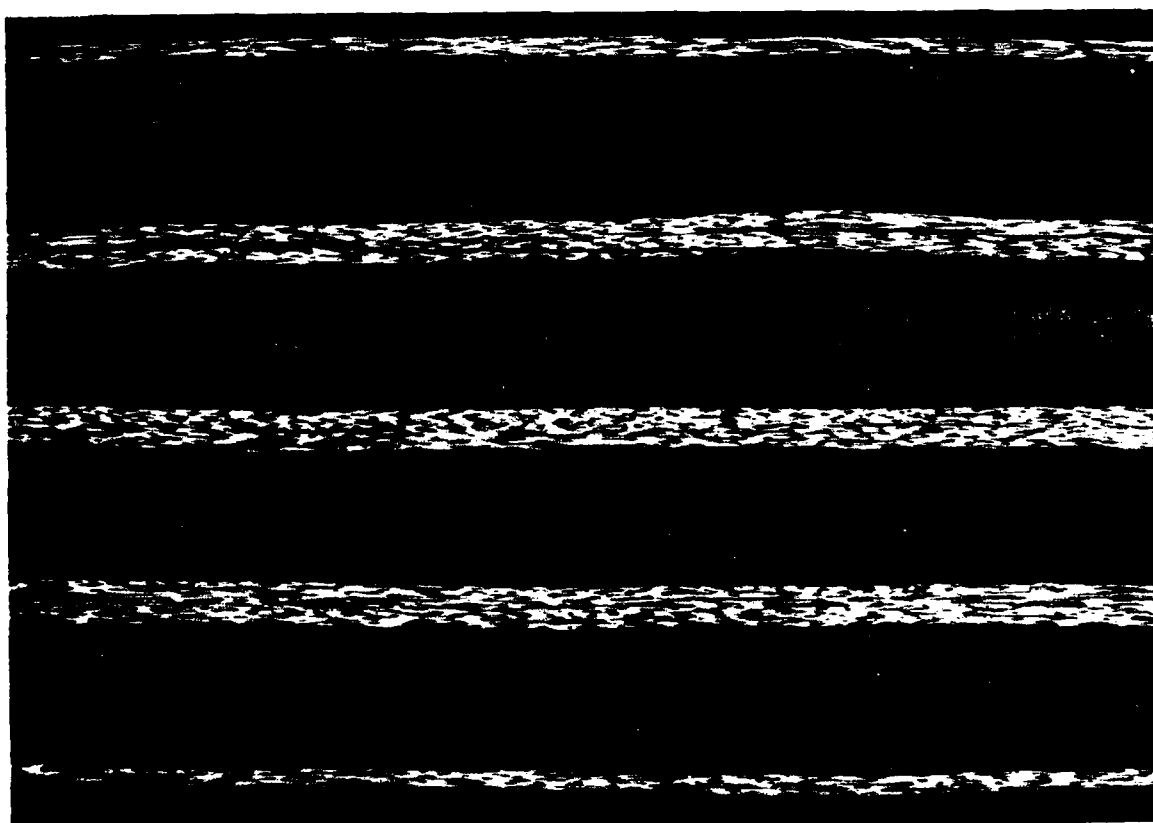
B-SCAN AT 1.16 IN.

LOCATION: 1.19 IN. DAMAGE LENGTH: 0.661



M22-7-1

10X

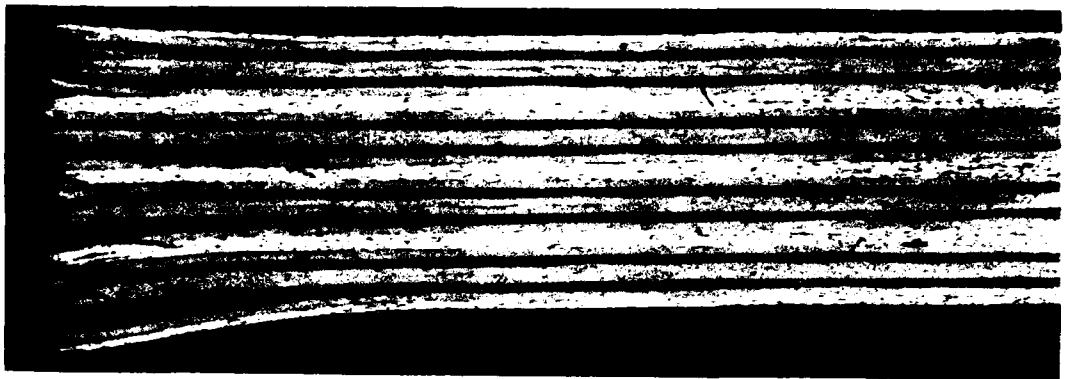


M22-7-2

25X

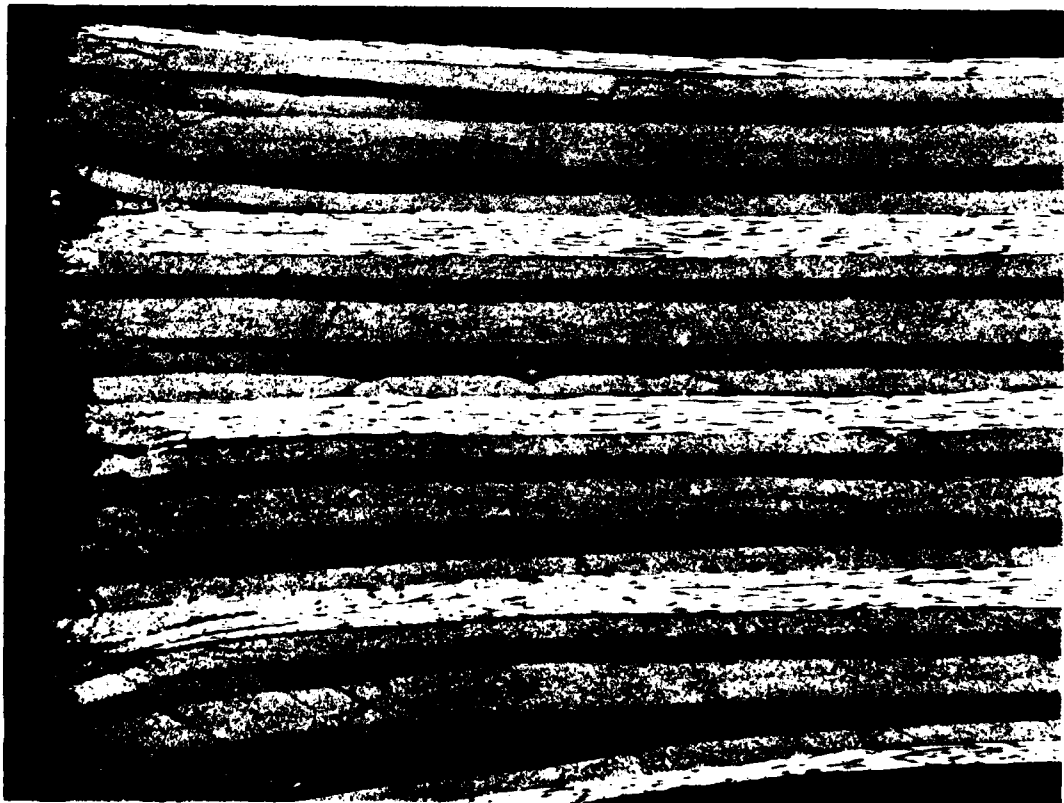
LOCATION: 1.29 IN. DAMAGE LENGTH: 0.681

G99



M22-8-1A

10X

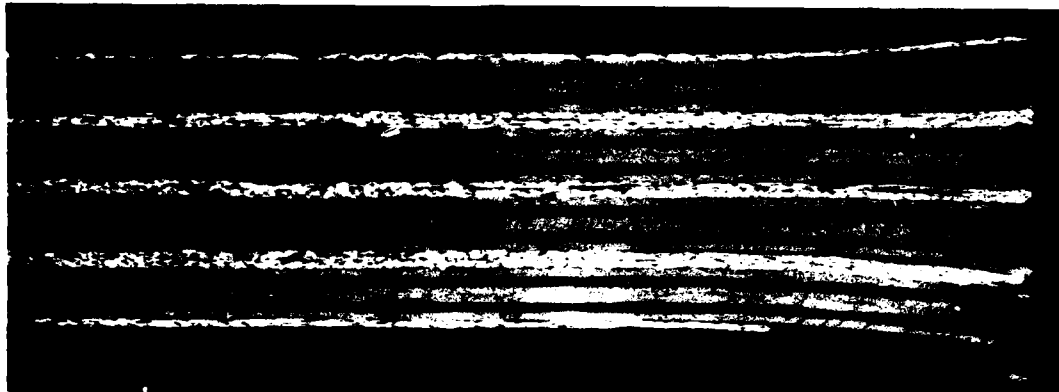


M22-8-1A

25X

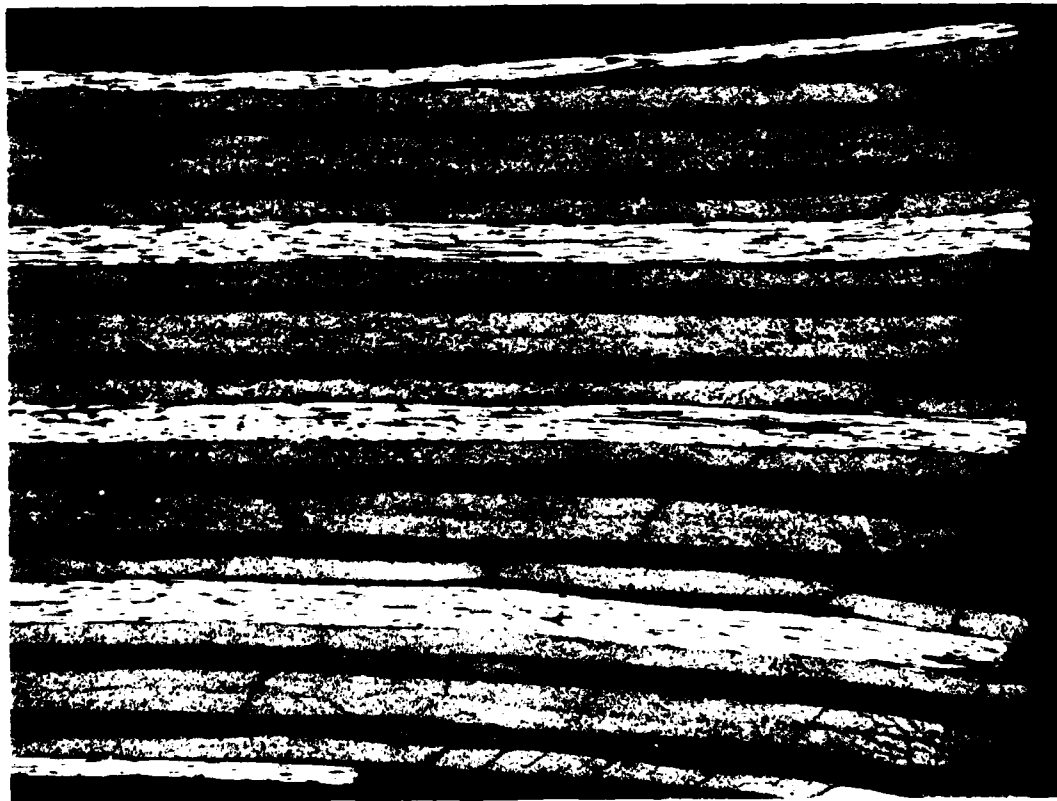
LOCATION: 1.39 IN. DAMAGE LENGTH: 0.756

G100



M22-8-2B

10X



M22-8-2P

25X

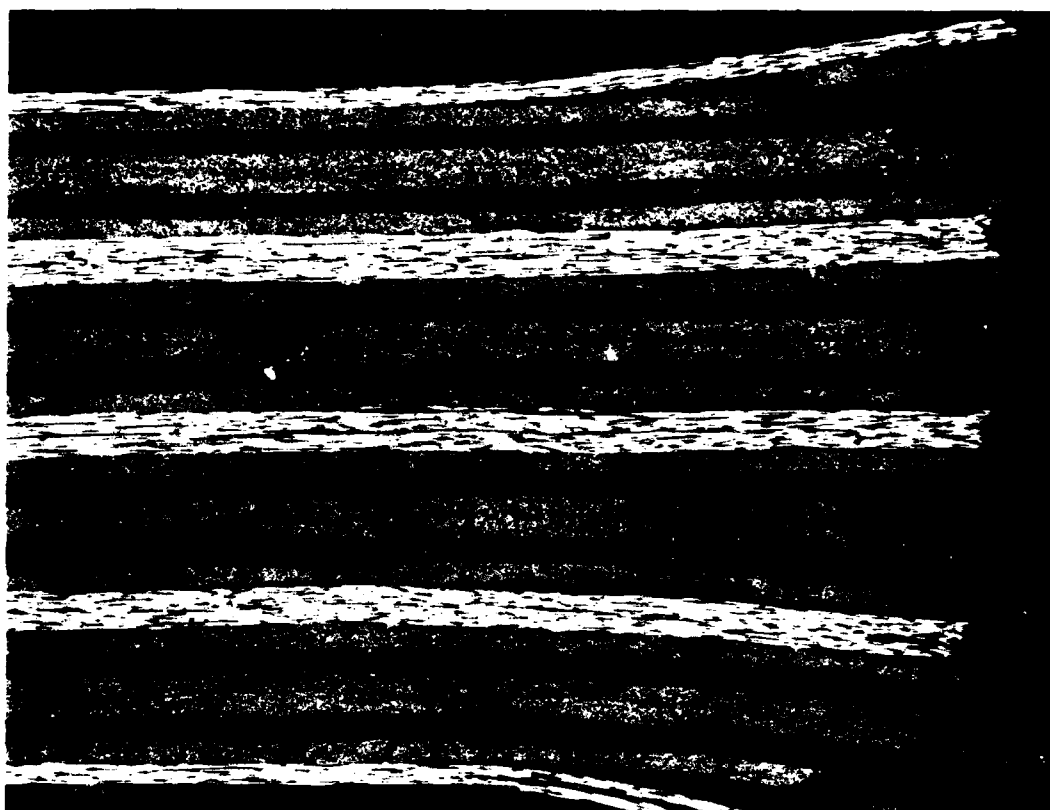
LOCATION: 1.39 IN. DAMAGE LENGTH: 0.756

G101



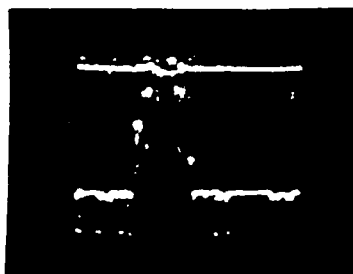
122-9-1A

10Y



122-9-2A

25Y



B-SCAN AT CENTER

LOCATION: 1.40 IN. DAMAGE LENGTH: 0.1

AD-A115 106

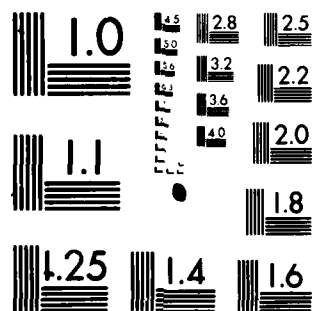
LOCKHEED-CALIFORNIA CO. BURBANK
ADVANCED RESIDUAL STRENGTH DEGRADATION RATE MODELING FOR ADVANC--ETC(U)
JUL 81 K M LAURITIS, J T RYDER, D E PETTIT F33615-77-C-3084
LR-28340-10 AFVAL-TR-79-3095-VOL-3 NL

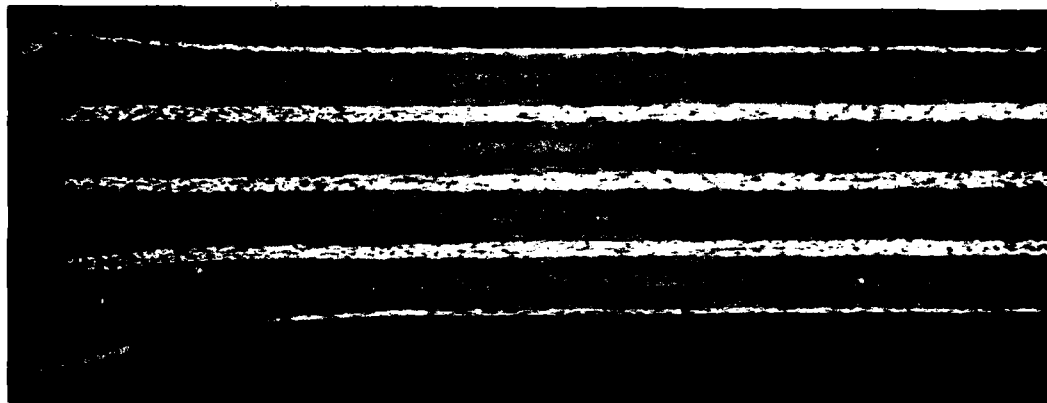
UNCLASSIFIED

4-5
22/10/81



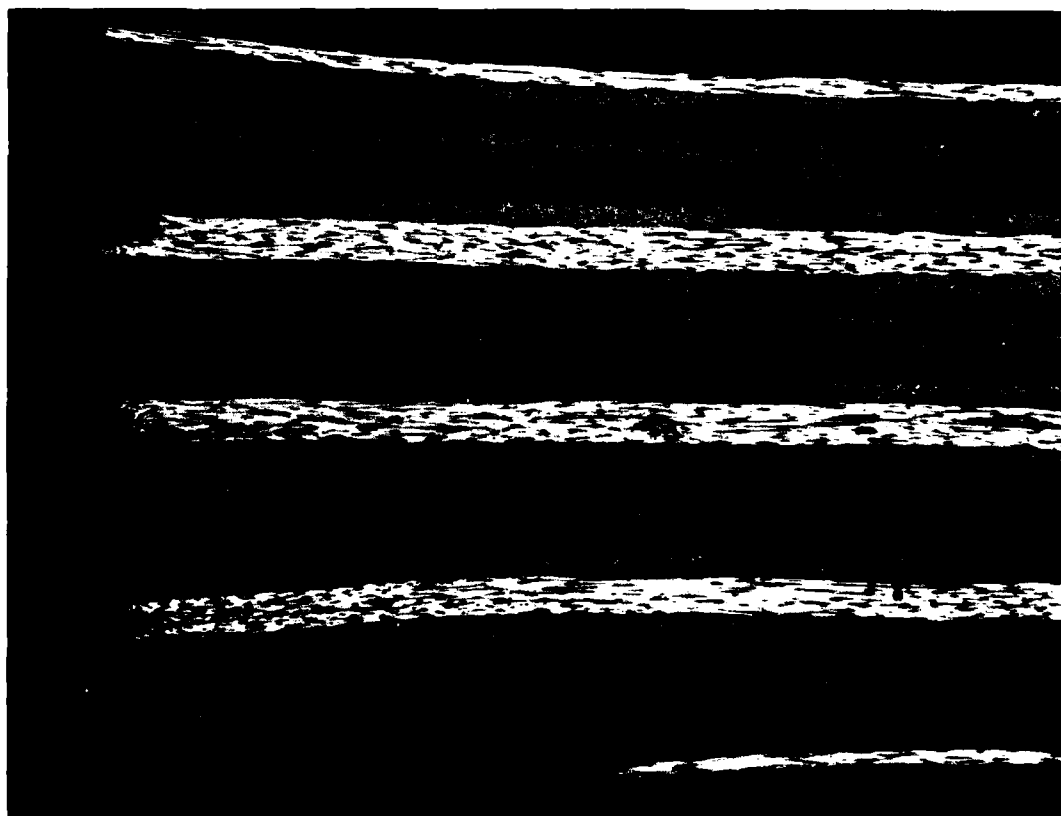
11518





M22-9-1B

10X

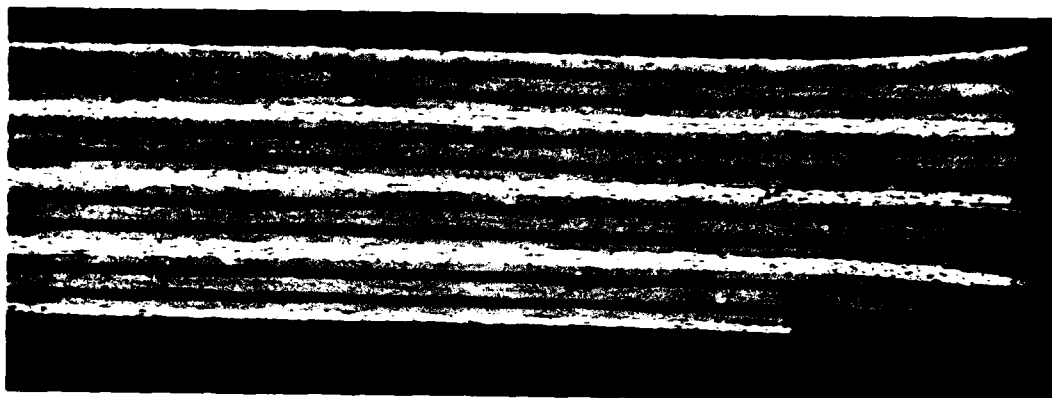


M22-9-2B

25X

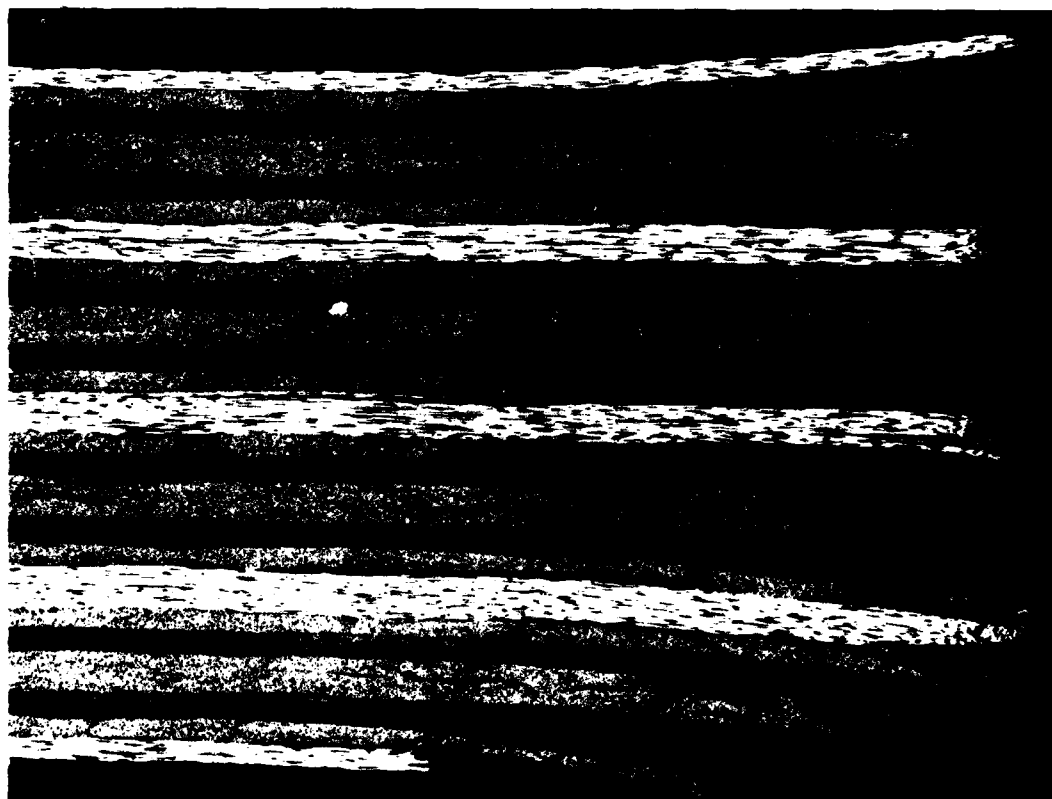
LOCATION: 1.49 IN. DAMAGE LENGTH: 0.780

G103



M22-10-1A

10X



M22-10-2A

25X

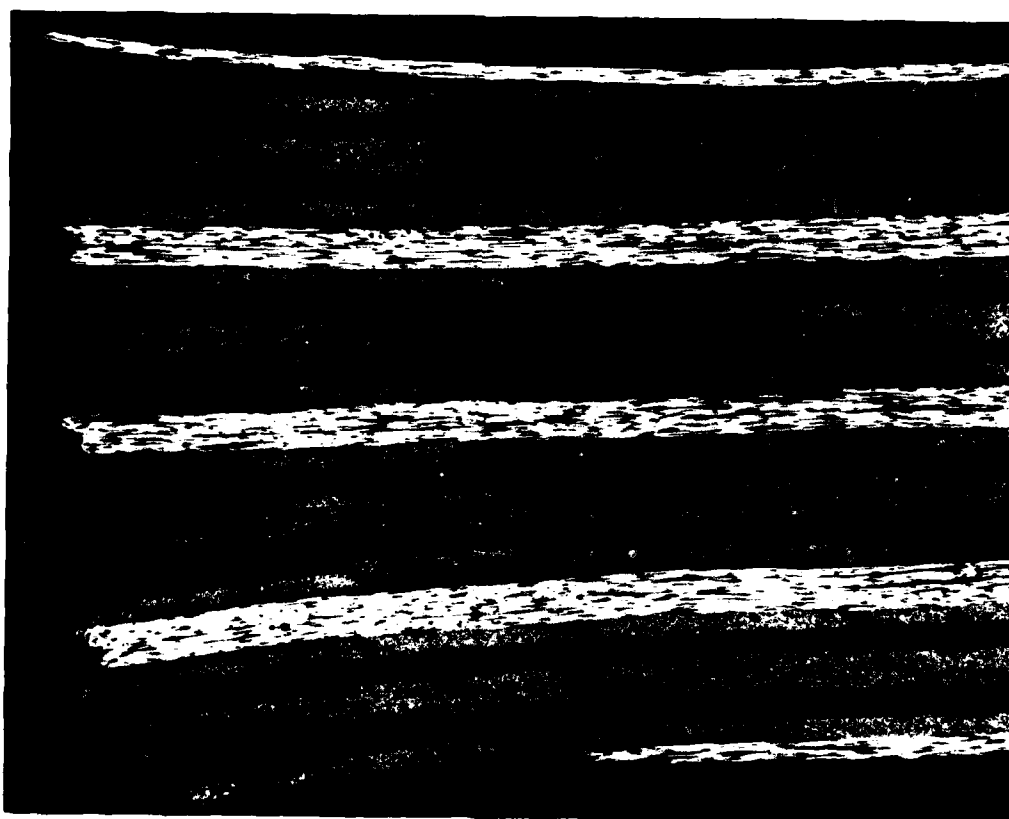
LOCATION: 1.59 IN. DAMAGE LENGTH: 0.793

G104



M22-10-1B

10X

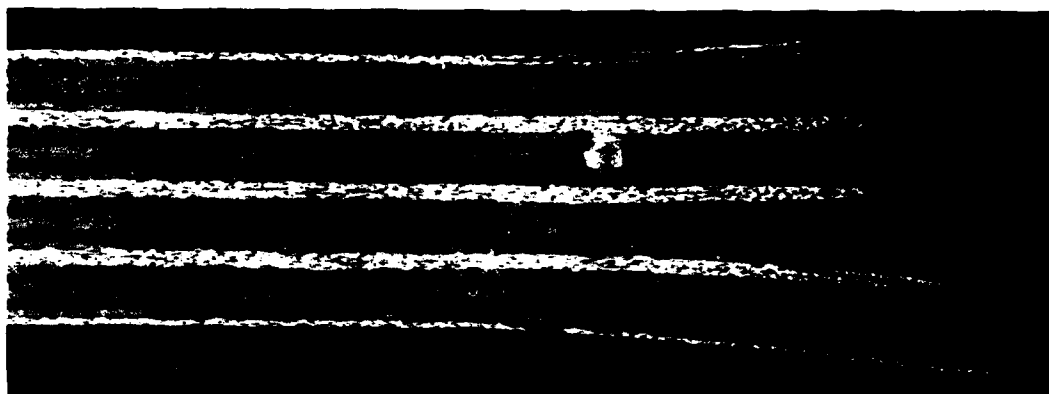


M22-10-2B

25X

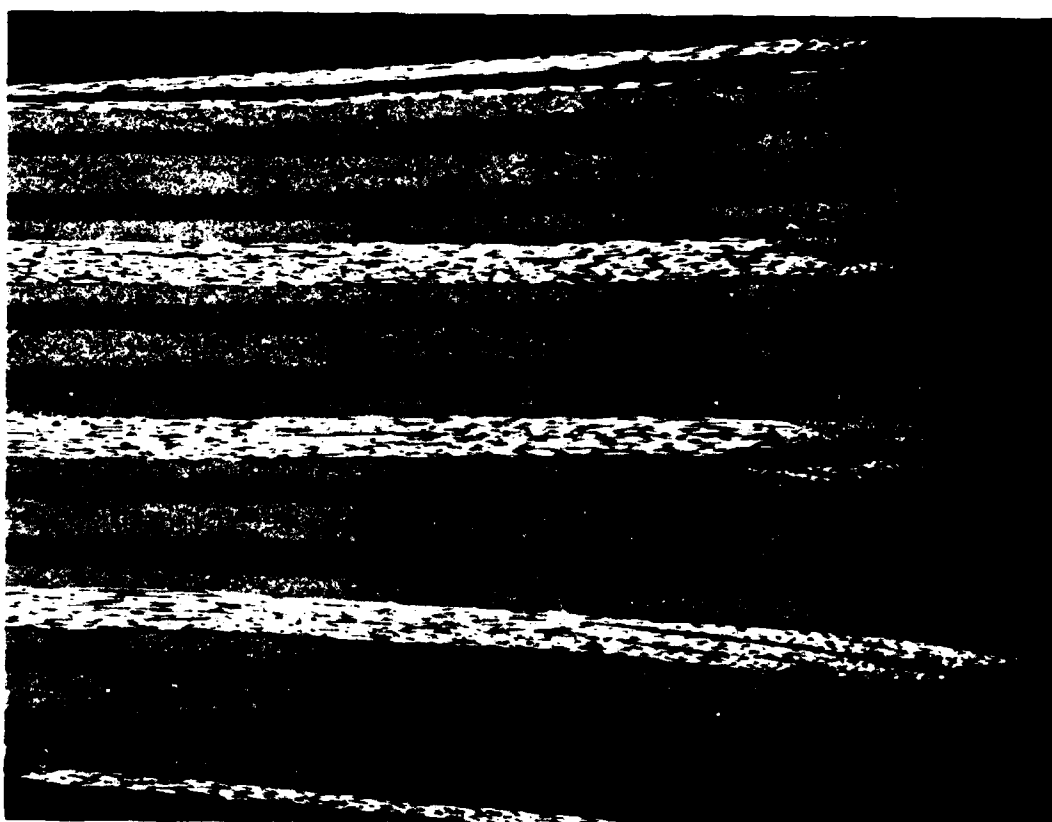
LOCATION: 1.59 IN. DAMAGE LENGTH: 0.793

G105



M22-11-1A

10X



M22-11-2A

25X

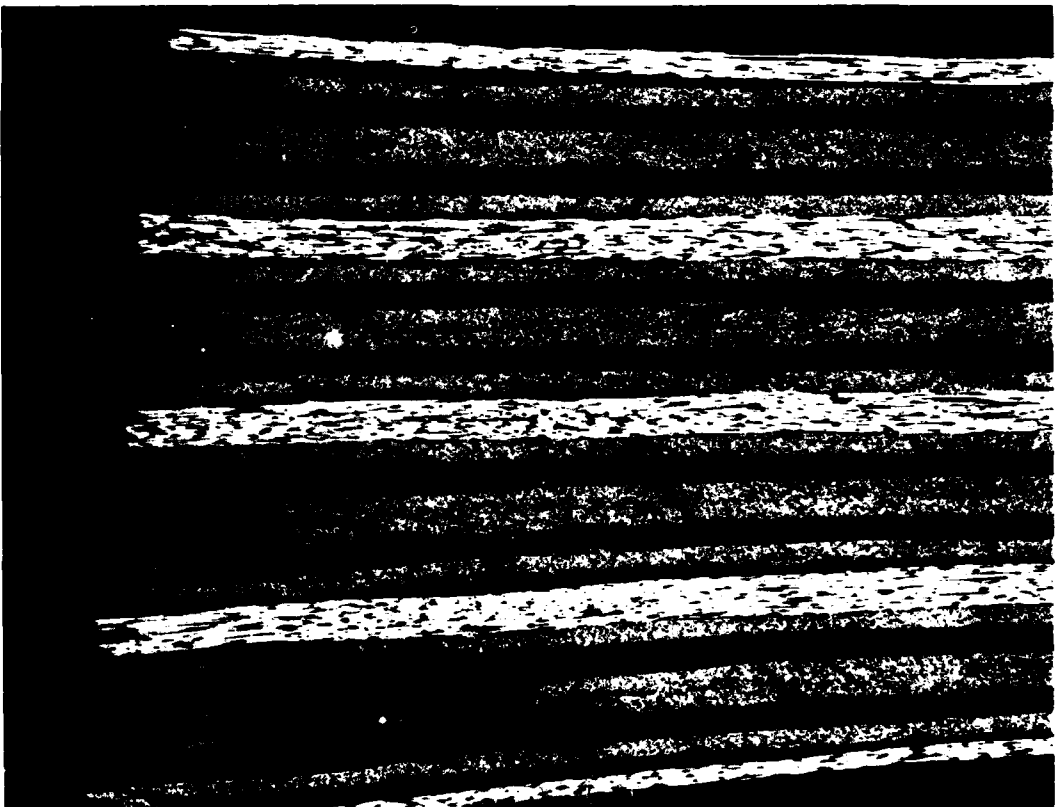
LOCATION: 1.69 IN. DAMAGE LENGTH: 0.726

G106



M22-11-1B

10X



M22-11-2P

25X

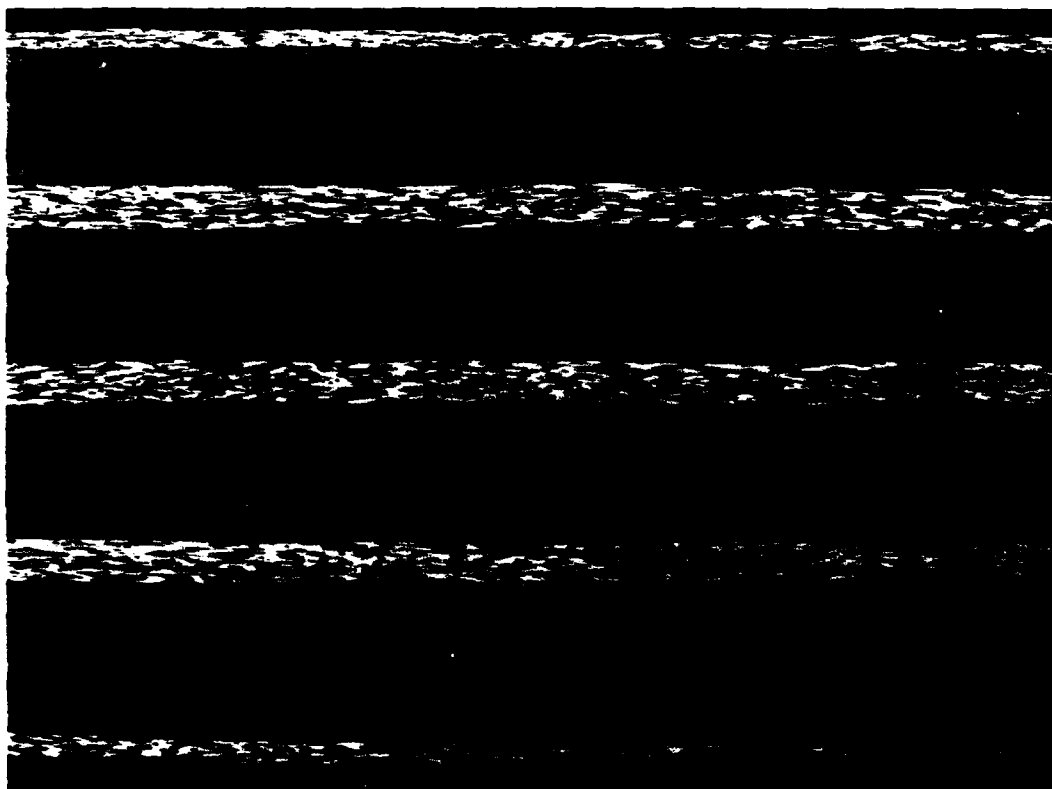
LOCATION: 1.69 IN. DAMAGE LENGTH: 0.726

G107



M22-12-1

10X

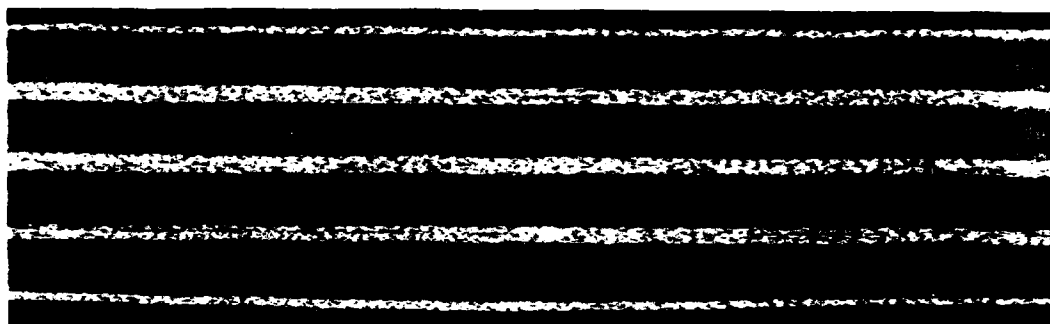


M22-12-2

25X

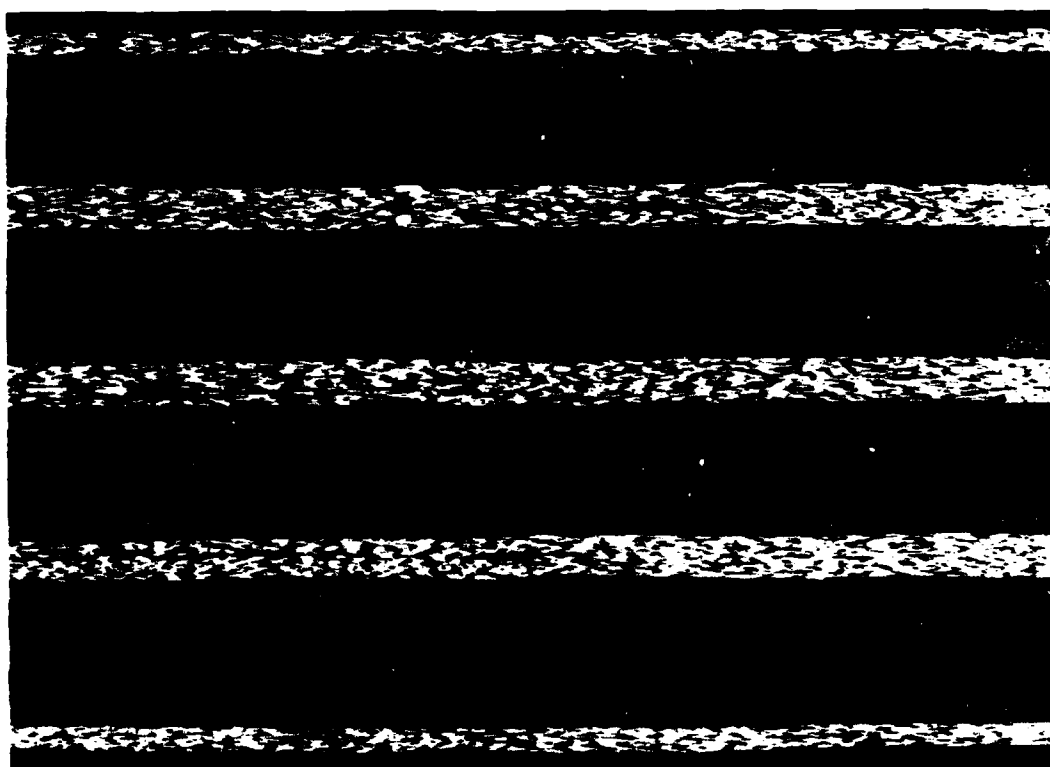
LOCATION: 1.79 IN. DAMAGE LENGTH: 0.754

G108



M22-13-1

10X



M22-13-2

25X

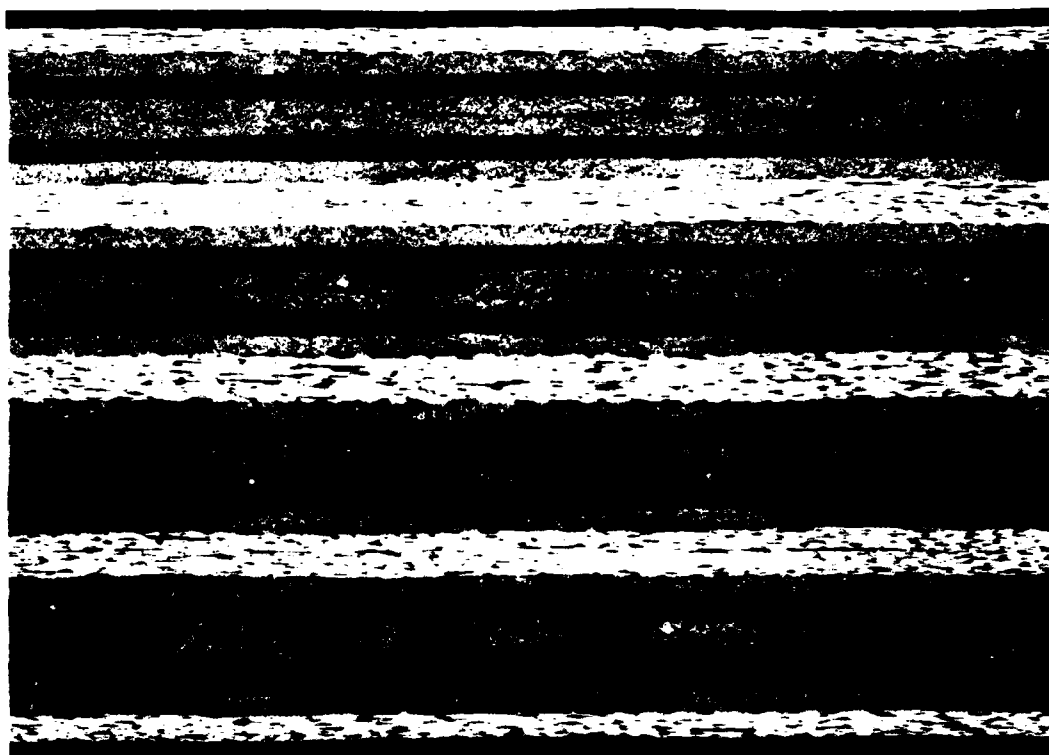
LOCATION: 1.89 in. DAMAGE LENGTH: 0.689

G109



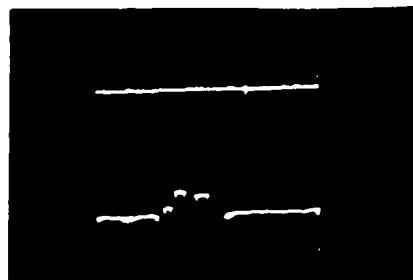
M22-14-1

10X



M22-14-2

25X



B-SCAN AT 1.95 IN.

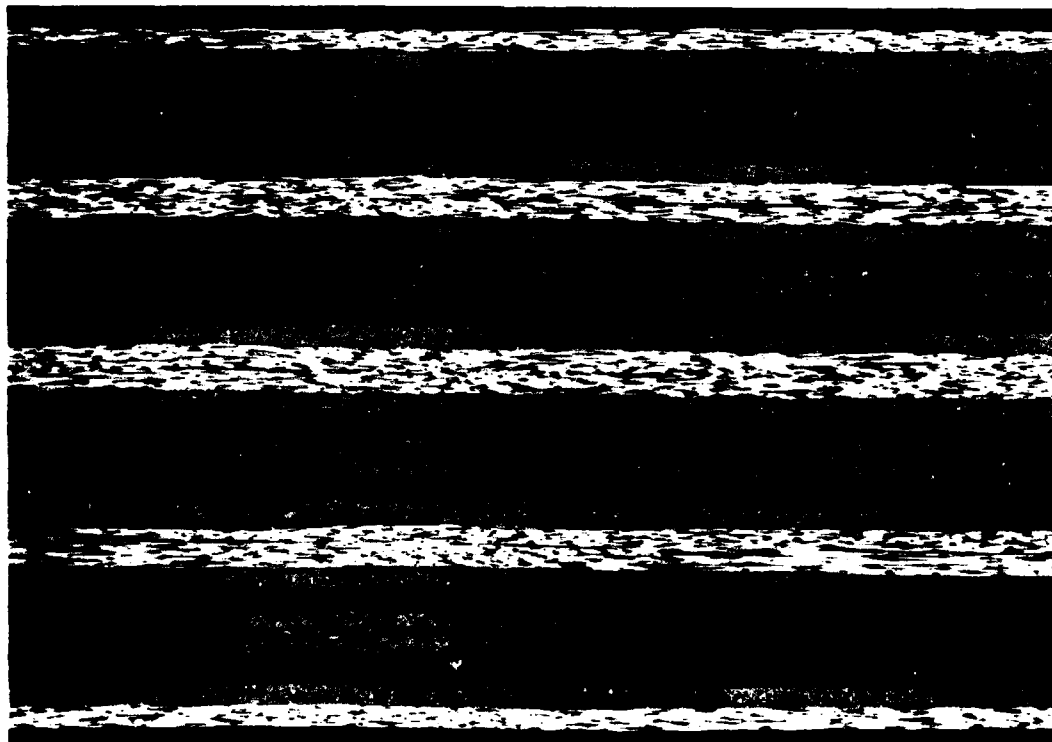
LOCATION: 1.99 IN. DAMAGE LENGTH: 0.641

G110



M22-15-1

10X

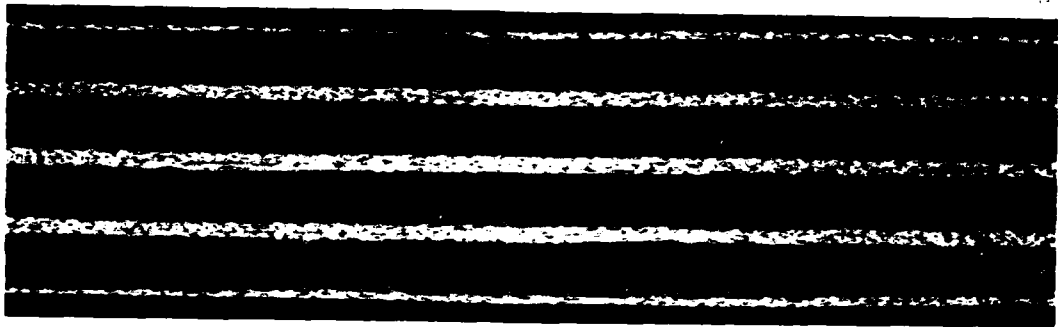


M22-15-2

25X

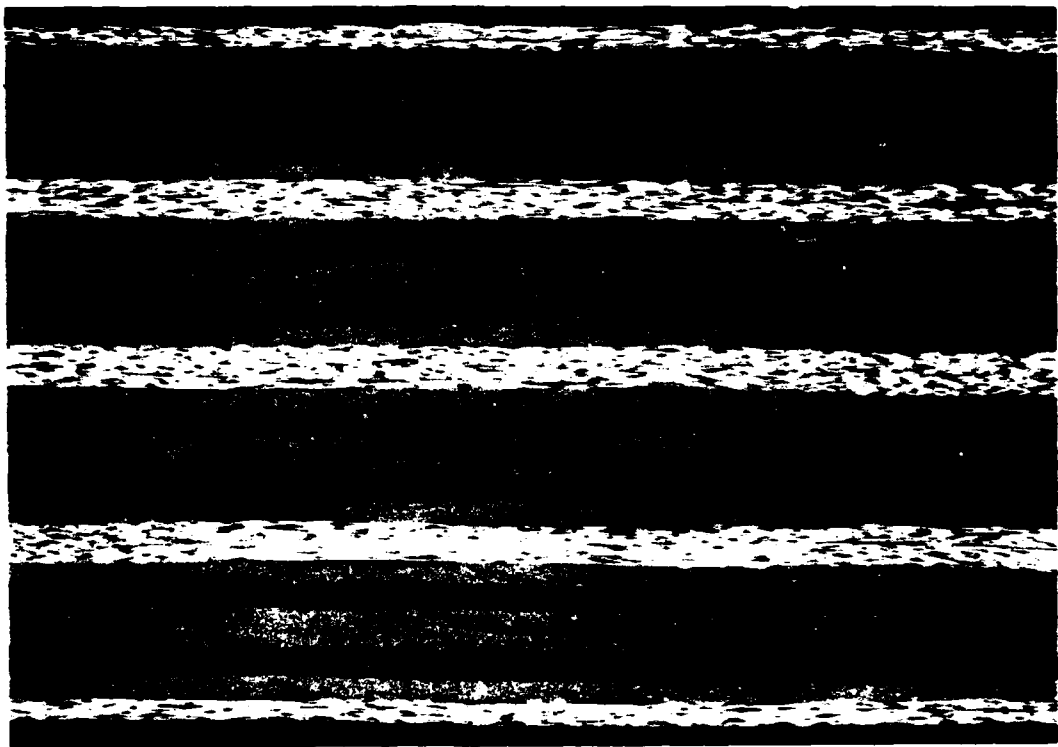
LOCATION: 2.09 IN. DAMAGE LENGTH: 0.554

G111



M22-16-1A

10X



M22-16-2A

25X

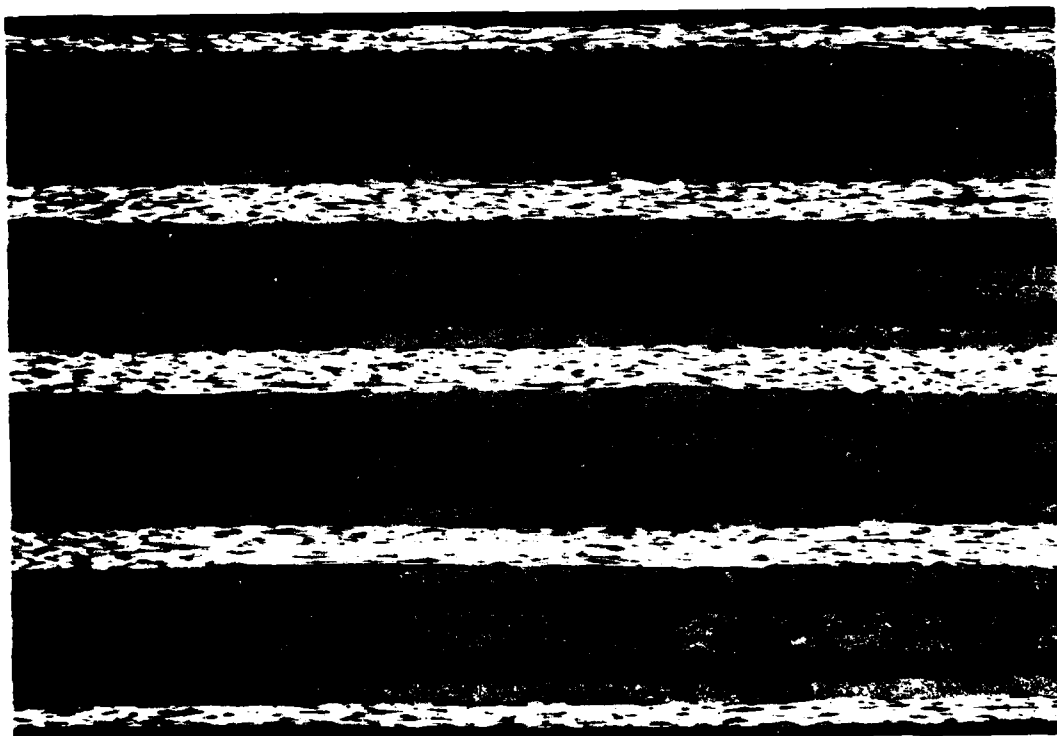
LOCATION: 2.19 in. DAMAGE LENGTH: 0.390

G112



M22-16-1B

10X



M22-16-2B

25X

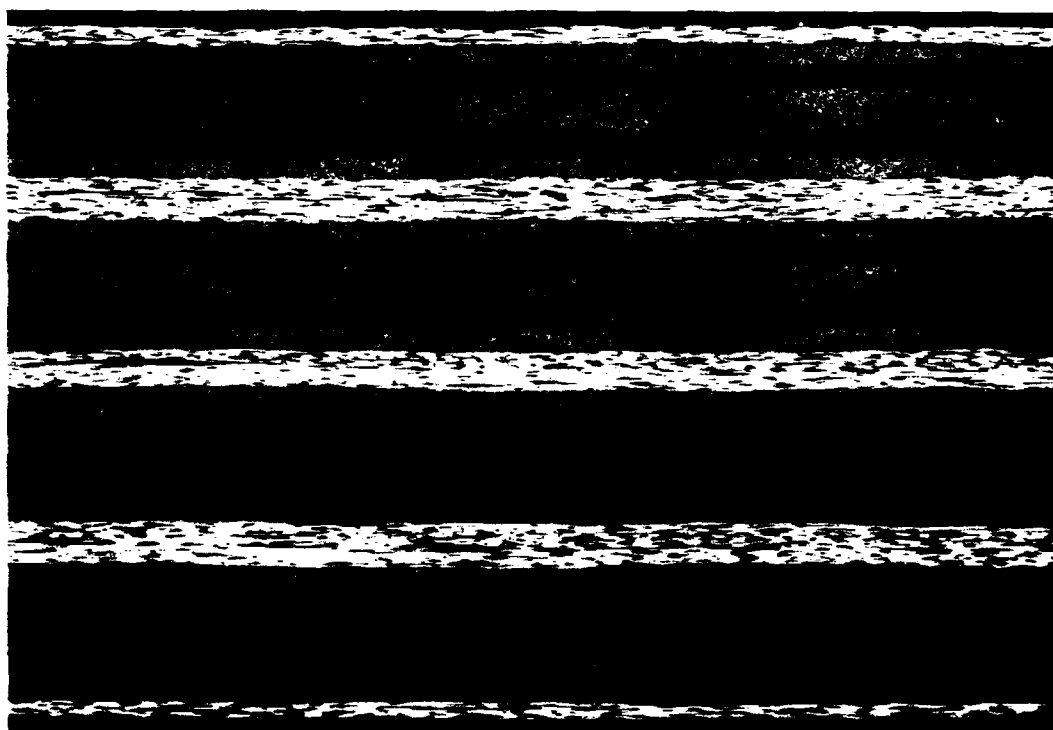
LOCATION: 2.19 IN. DAMAGE LENGTH: 0.390

G113



M22-17-1

10X

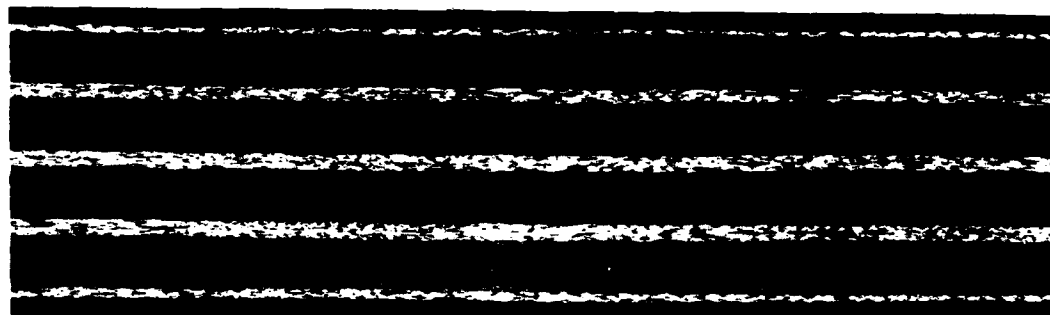


M22-17-2

25X

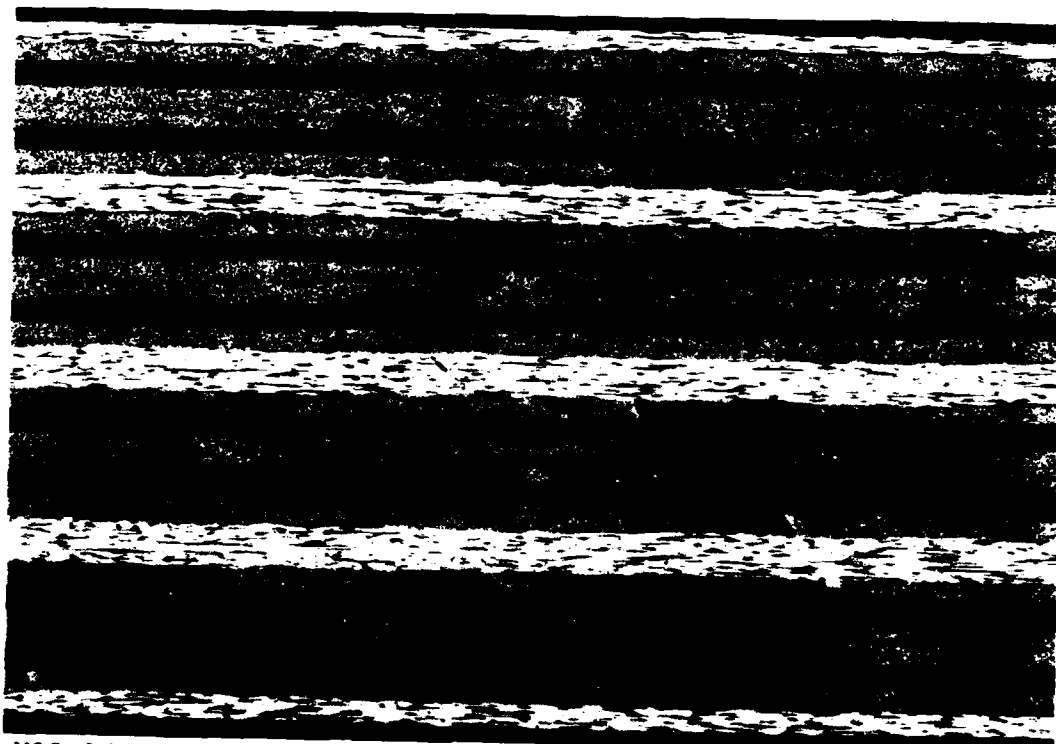
LOCATION: 2.29 IN. DAMAGE LENGTH: 0.325

G114



M22-18-1

10X



M22-18-2

25X

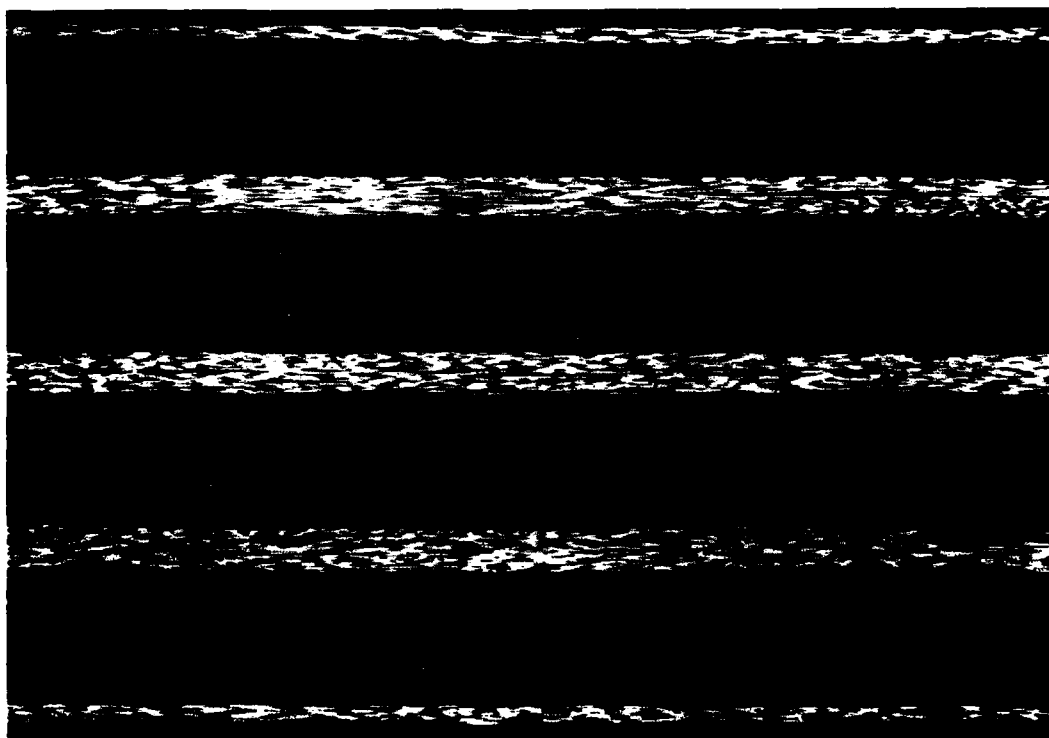
LOCATION: 2.39 IN. DAMAGE LENGTH: 0.115

G115



M22-19-1

10X



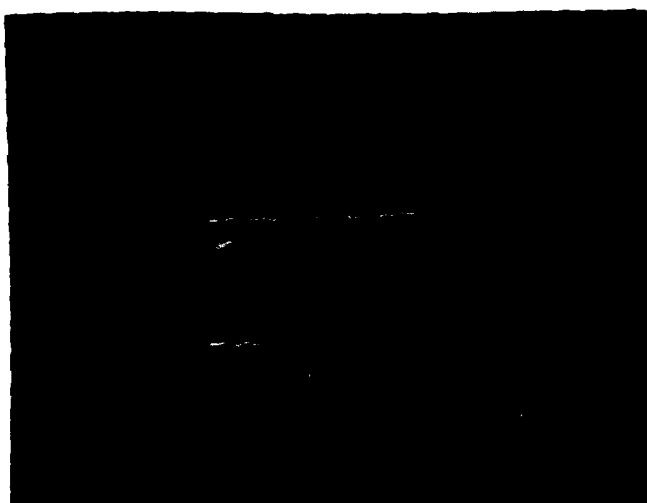
M22-19-2

25X

LOCATION: 2.49 IN. DAMAGE LENGTH: NO DAMAGE



C-SCAN



CUMULATIVE B-SCAN

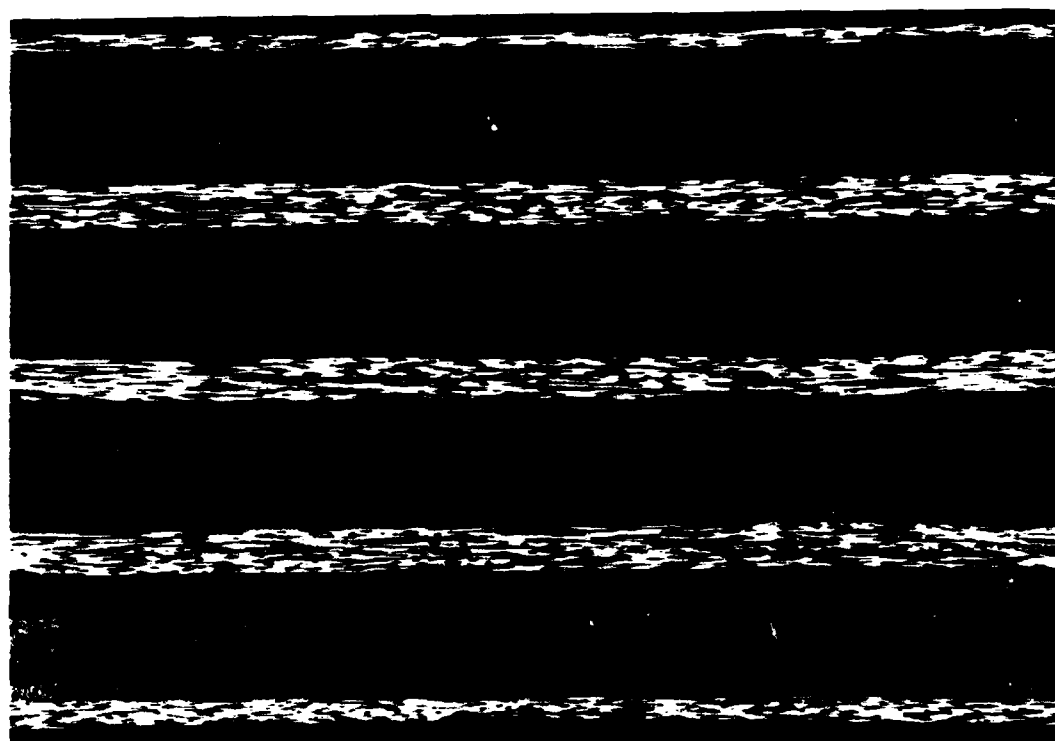
32-PLY SPEC: RC-23 $N_3 = 10,000$ CYCLES

G117



R23-1-1

10X

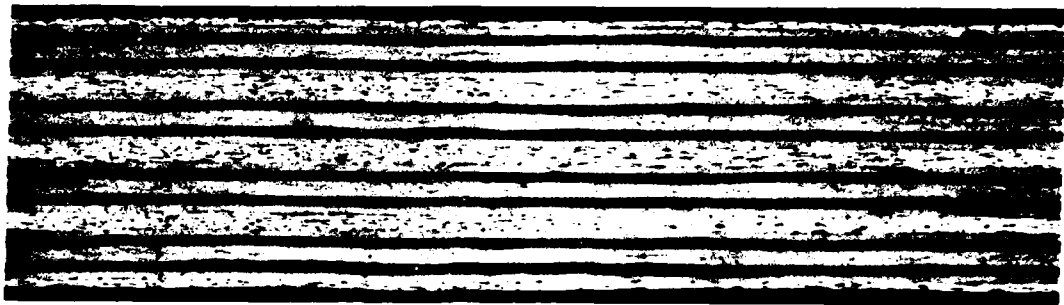


R23-1-2

25X

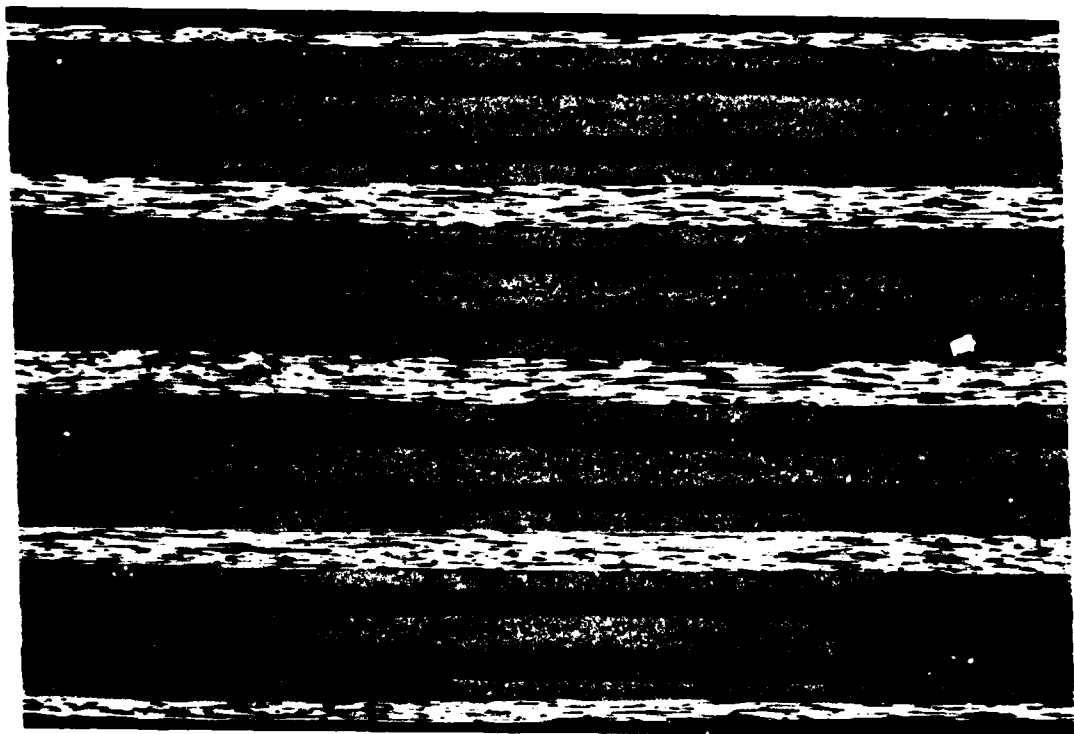
LOCATION: 0.61 IN. DAMAGE LENGTH: 0.237

G118



R23-2-1

10X



R23-2-2

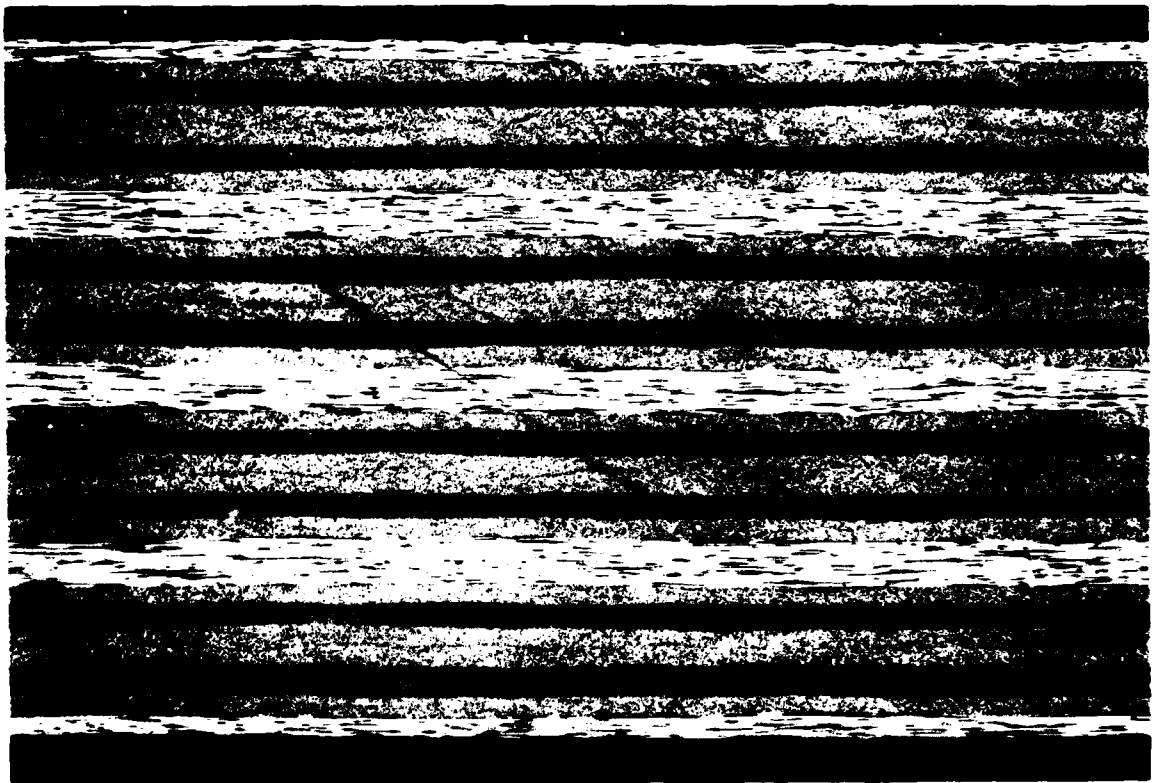
25X

LOCATION: 0.71 IN. DAMAGE LENGTH: 0.379



R23-3-1

10X

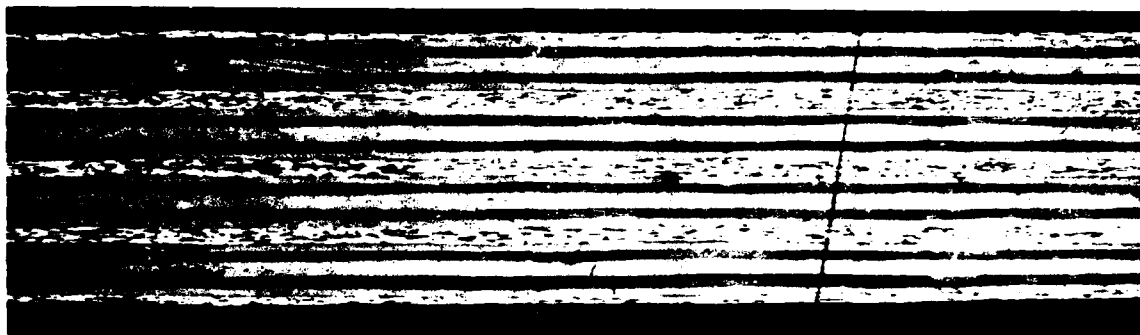


P23-3-2

25X

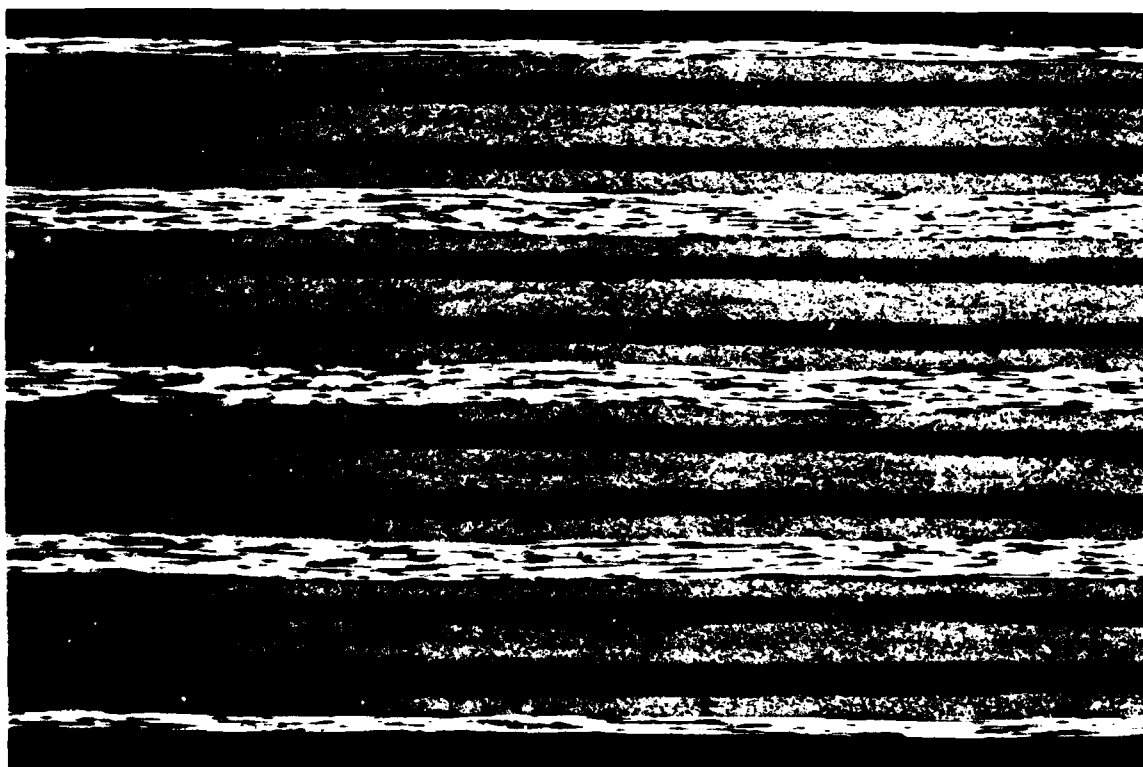
LOCATION: 0.81 DAMAGE LENGTH: 0.438

G120



R23-4-1

10X



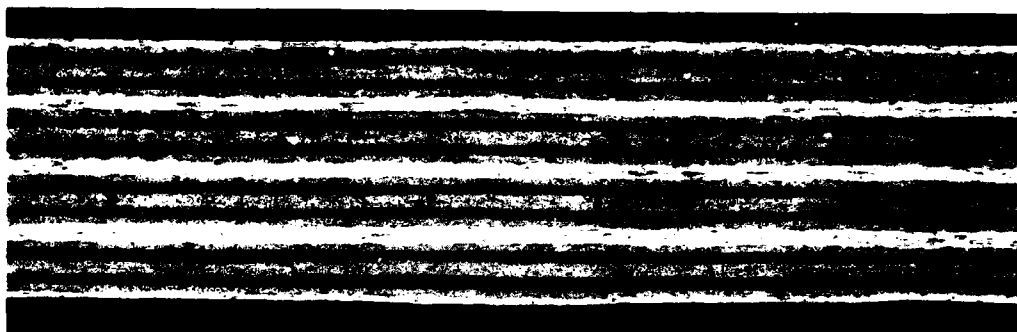
R23-4-2

25X

LOCATION: 0.91 IN. DAMAGE LENGTH: 0.859

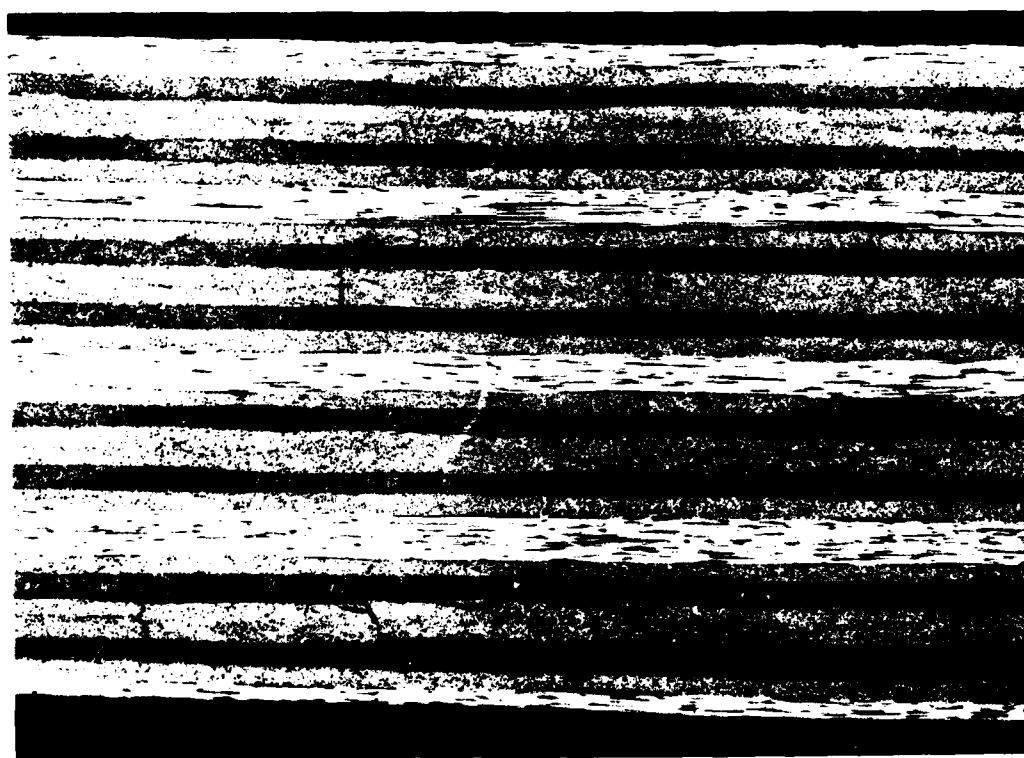
G121

LOCATION: 1.01 in. DAMAGE LENGTH: 0.677



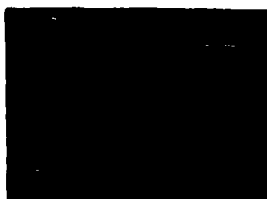
R23-5-1

10X



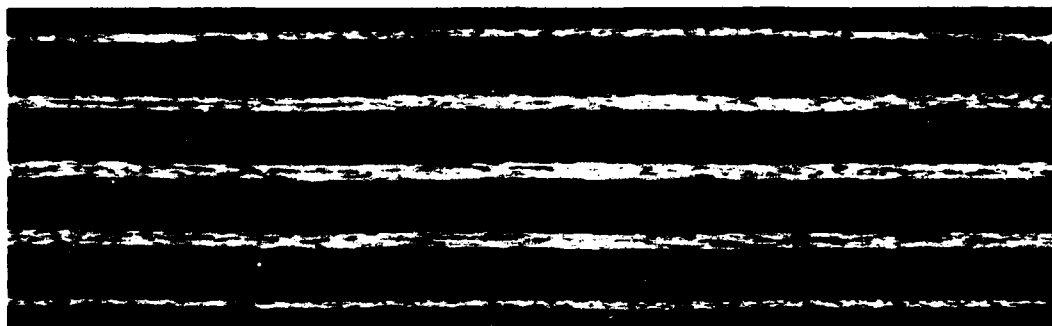
R23-5-2

25X



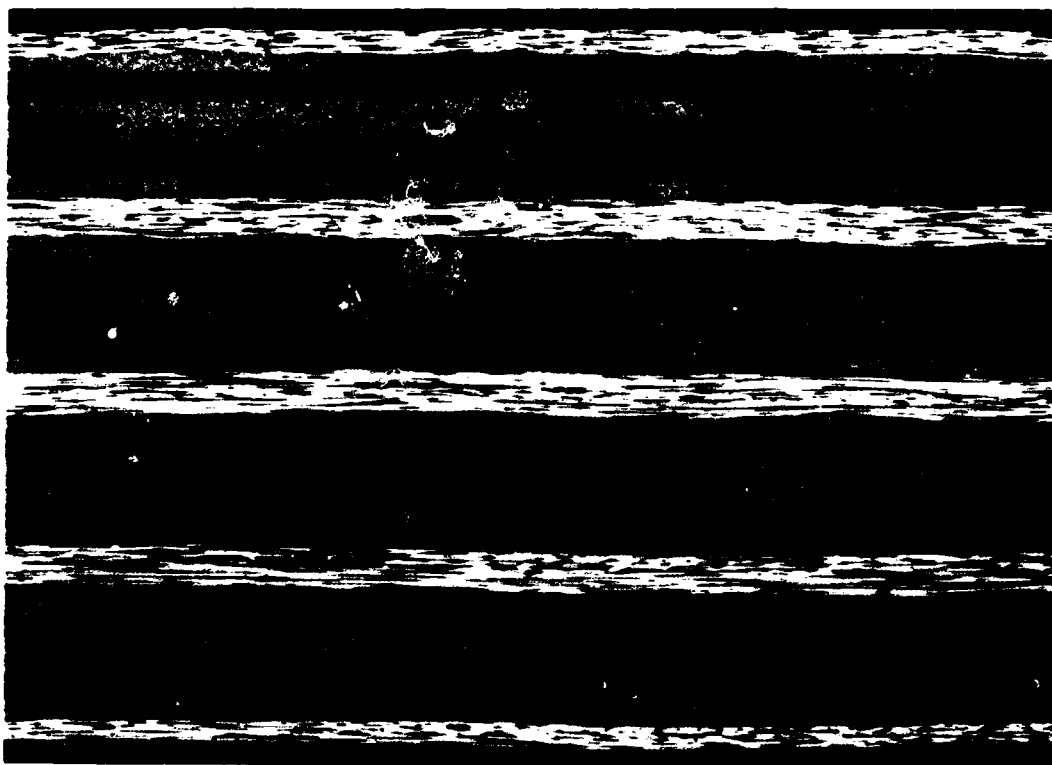
B-SCAN AT 1.04 in.

G122



R23-6-1

10X



R23-6-2

25X

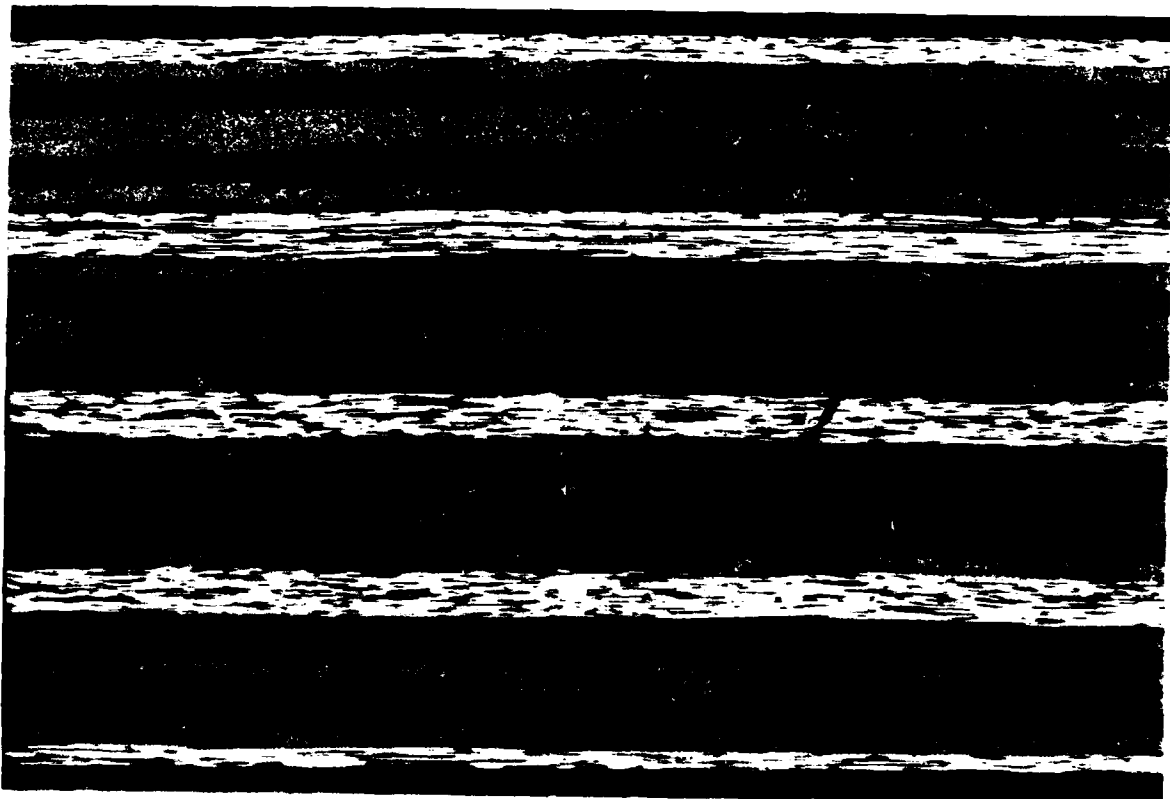
LOCATION: 1.11 in. DAMAGE LENGTH: 0.709

G123



P23-7-1

10X

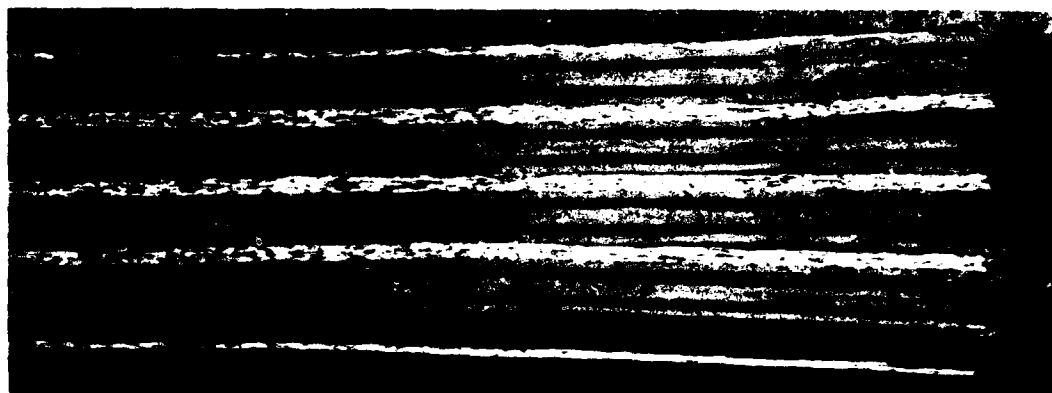


P23-7-2

25X

LOCATION: 1.21 IN. DAMAGE LENGTH: 0.734

G124



R23-8-1A

10X

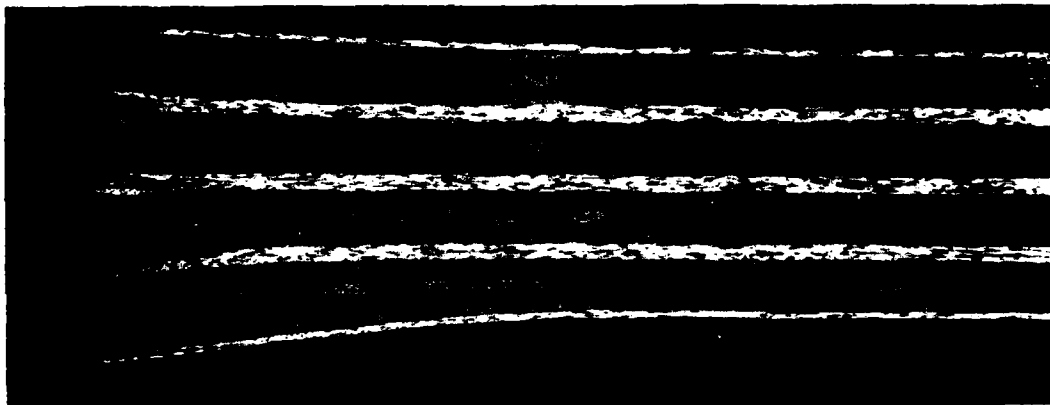


R23-8-2A

25X

LOCATION: 1.31 IN. DAMAGE LENGTH: 0.832

G125



R23-8-1B

10X

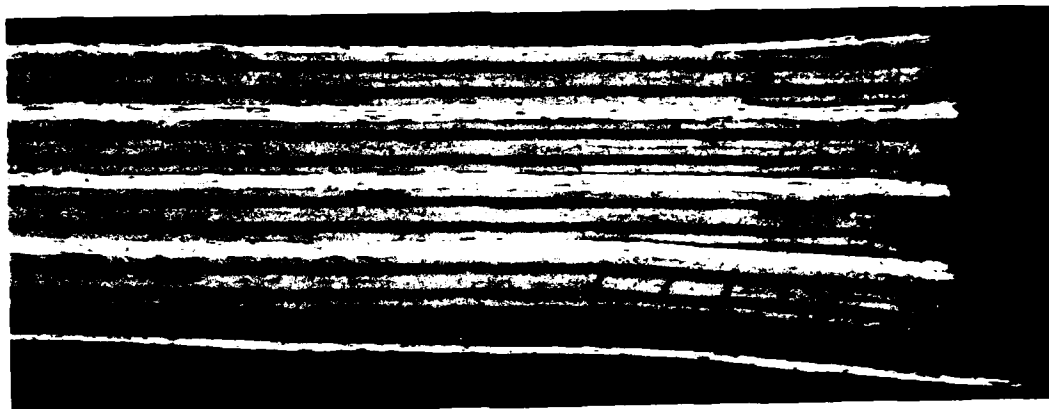


R23-8-2B

25X

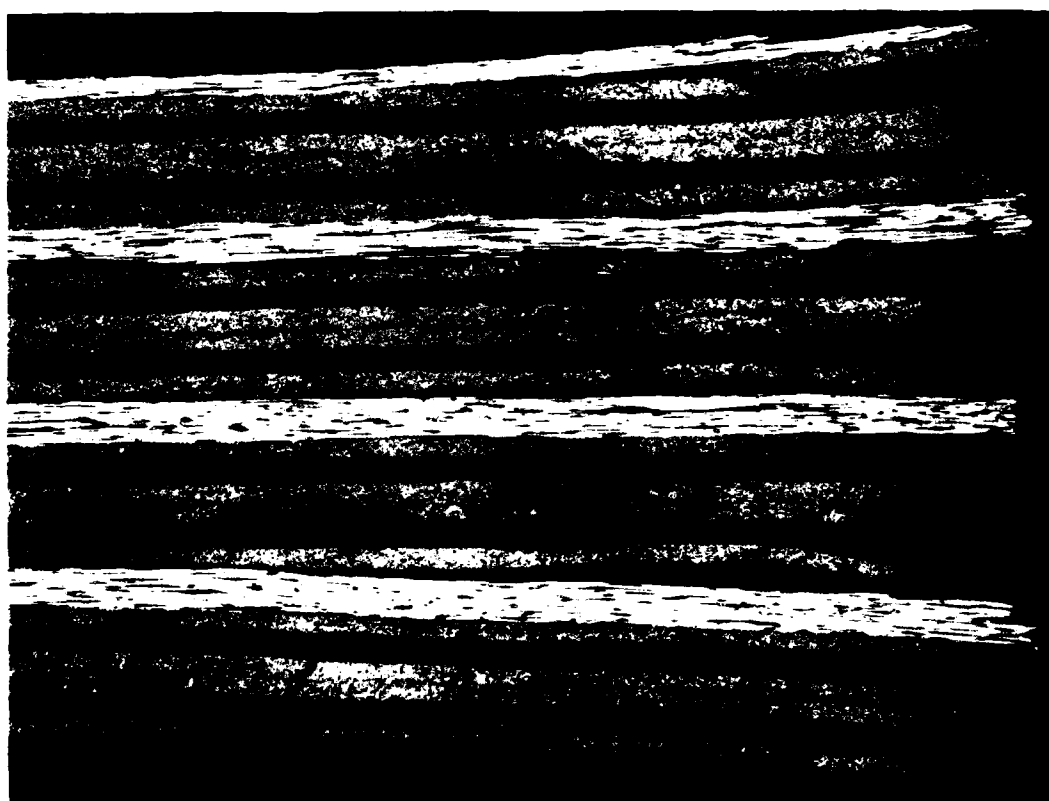
LOCATION: 1.31 in. DAMAGE LENGTH: 0.832

G126



R23-9-1A

10X



R23-9-2A

25X

LOCATION: 1.41 IN. DAMAGE LENGTH: 0.907

G127



R23-9-1B

10X

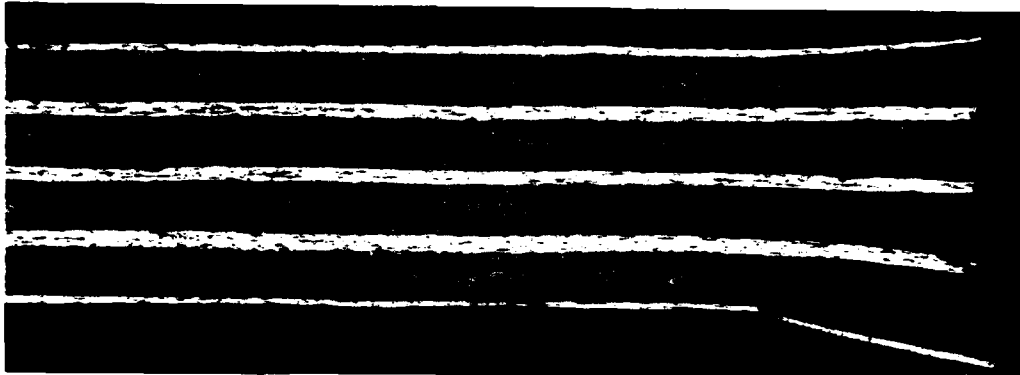


R23-9-2B

25X

LOCATION: 1.41 IN. DAMAGE LENGTH: 0.907
G128

LOCATION: 1.51 IN. DAMAGE LENGTH: 0.926



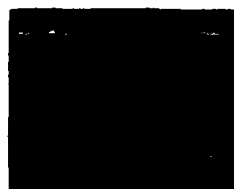
R23-10-1A

10X



R23-10-2A

25X



B-SCAN AT CENTER

G129



R23-10-1B

10X

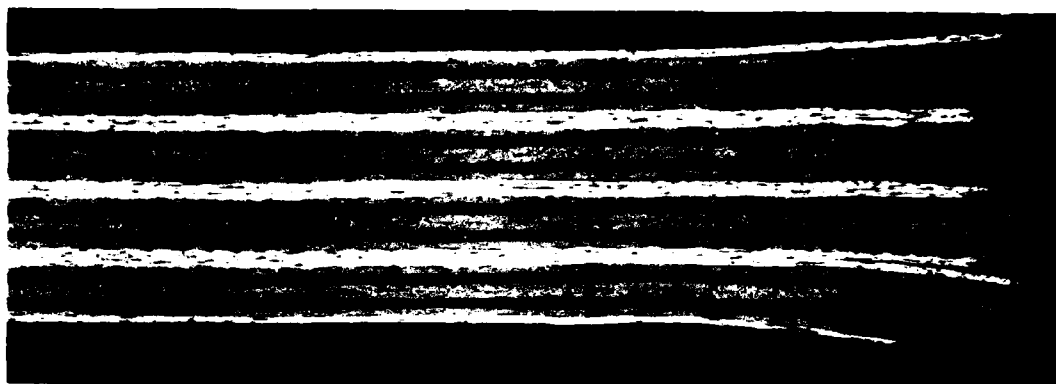


R23-10-2B

25X

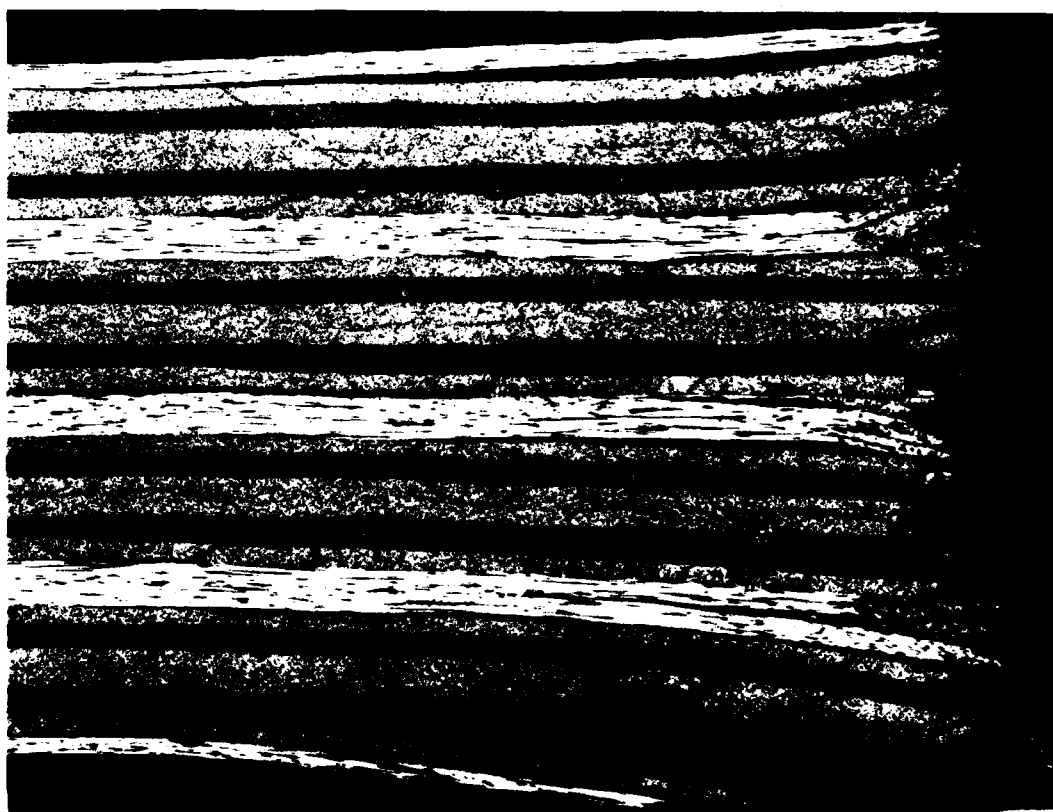
LOCATION: 1.51 IN. DAMAGE LENGTH: 0.926

G130



R23-11-1A

10X

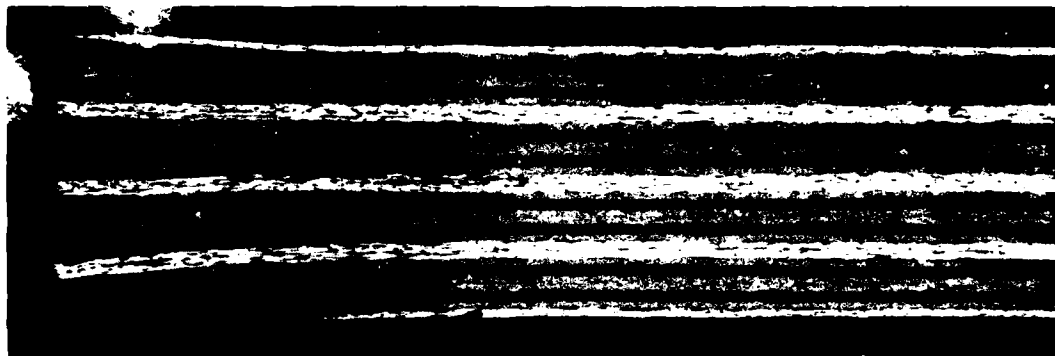


R23-11-2A

25X

LOCATION: 1.61 IN. DAMAGE LENGTH: 0.882

G131



R23-11-1B

10Y



P23-11-2B

25X

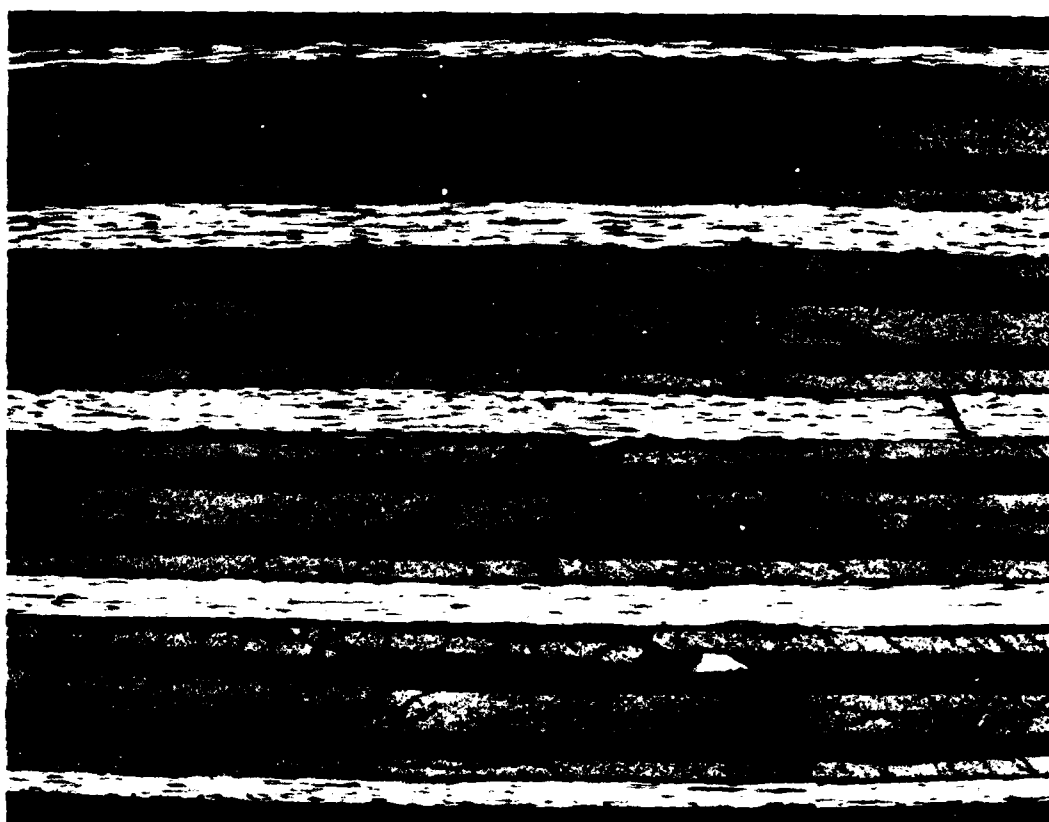
LOCATION: 1.61 IN. DAMAGE LENGTH: 0.882

G132



R23-12-1

10X

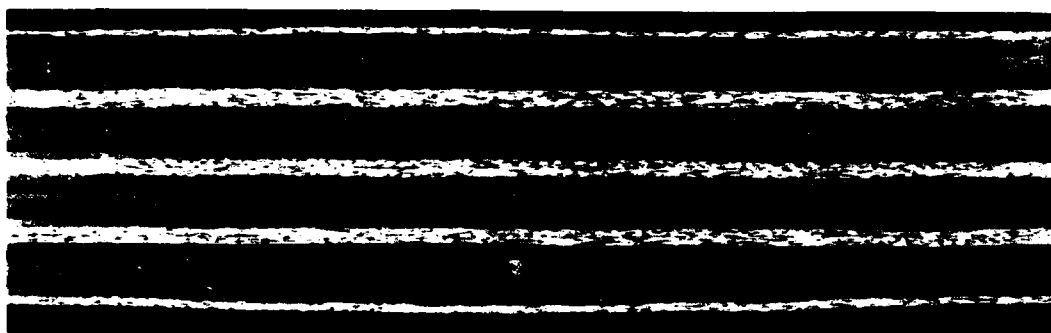


R23-12-2

25X

LOCATION: 1.71 IN. DAMAGE LENGTH: 0.763

G133



R23-13-1

10X



R23-13-2

25X

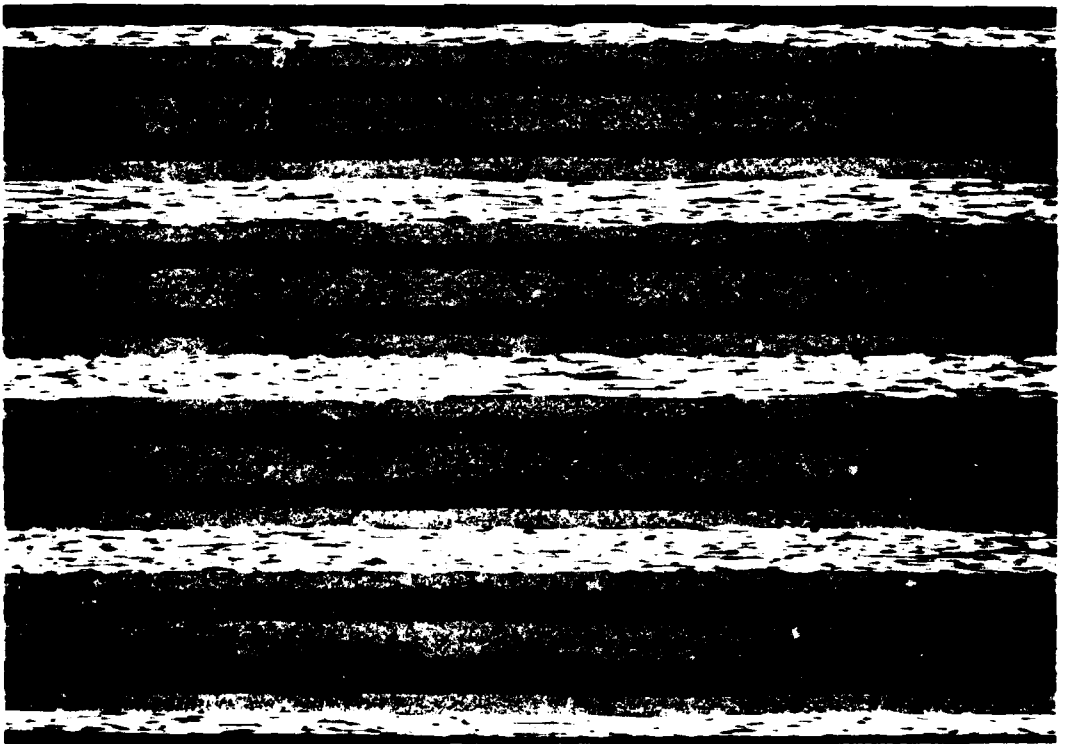
LOCATION: 1.81 IN. DAMAGE LENGTH: 0.702

G134



R23-14-1

10X



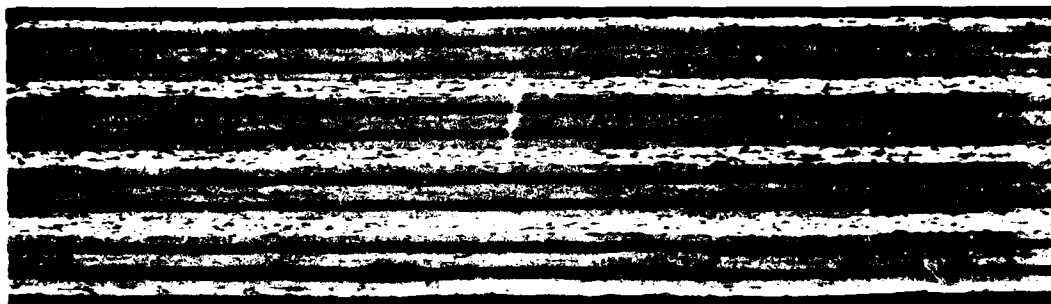
R23-14-2

25X

LOCATION: 1.91 in. DAMAGE LENGTH: 0.649

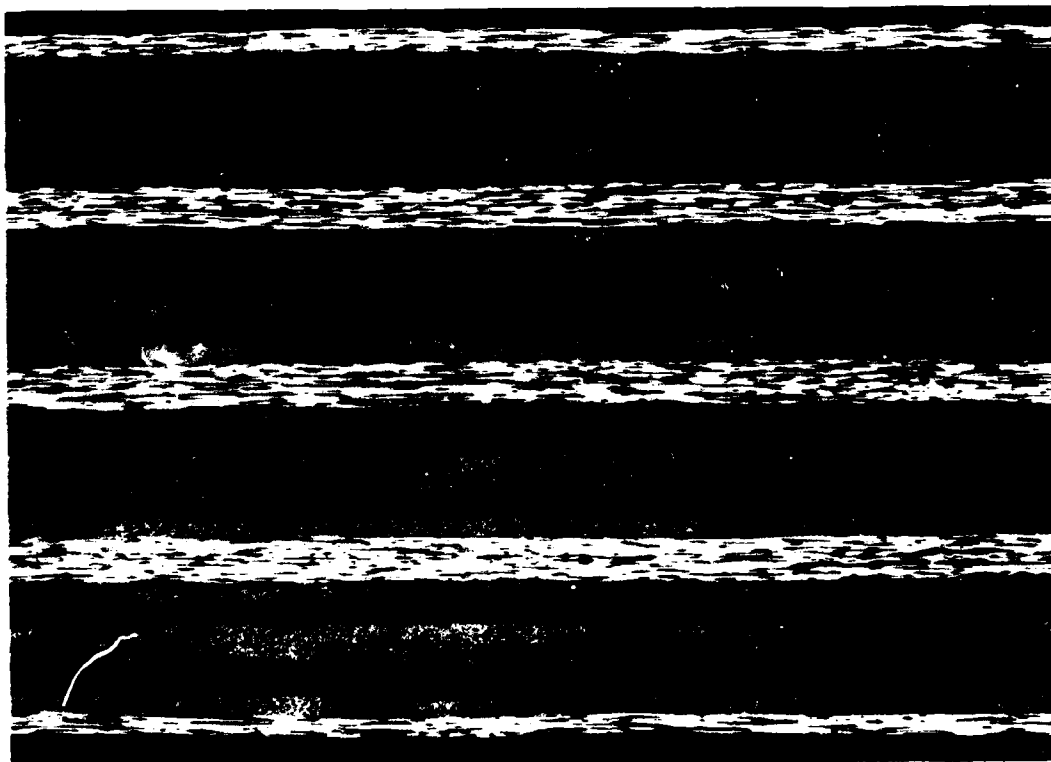
G135

LOCATION 2.01 IN. DAMAGE LENGTH: 0.635



R23-15-1

10X



R23-15-2

25X



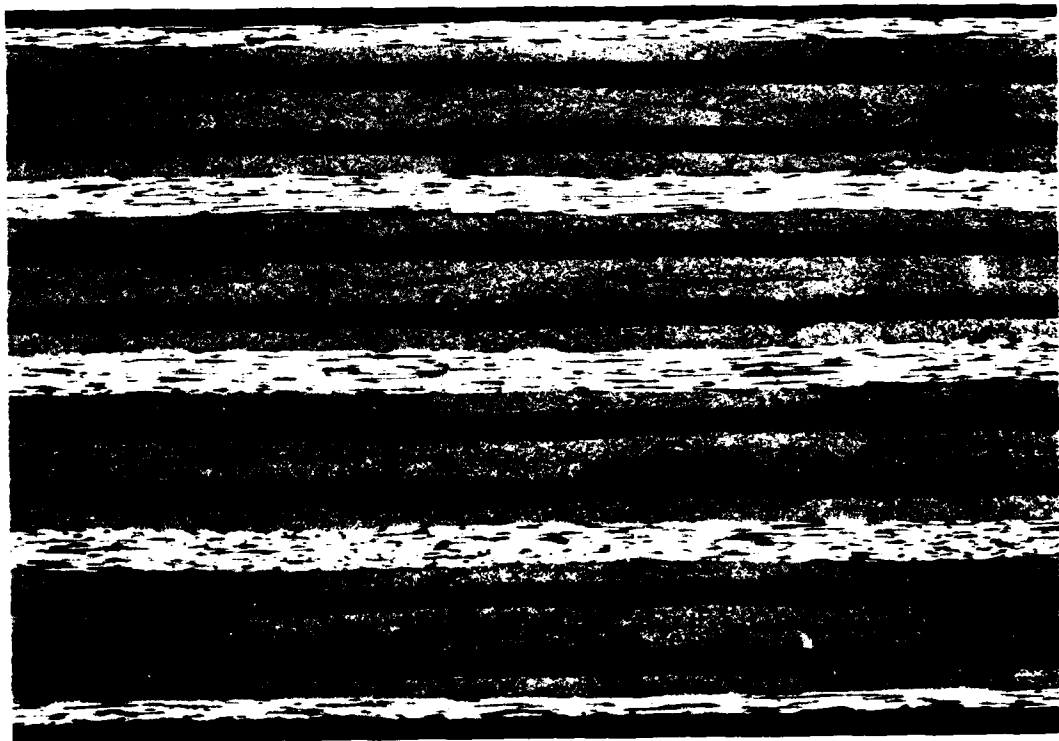
E-SCAN AT 2.02 IN.

G136



R23-16-1

10X



R23-16-2

25X

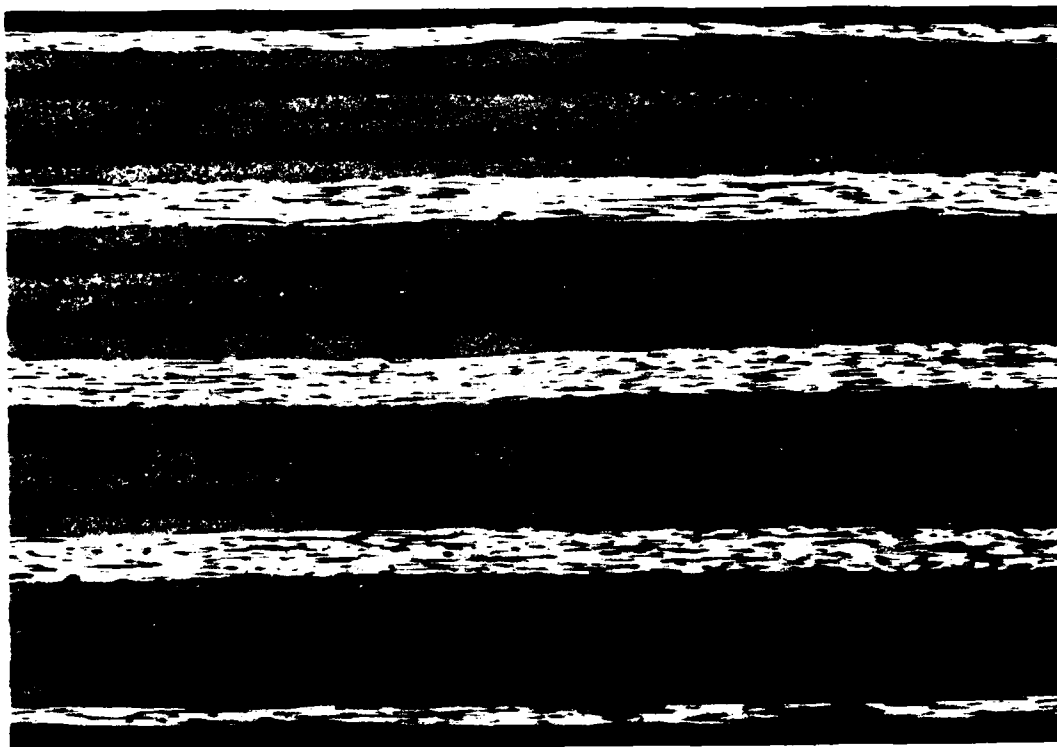
LOCATION: 2.11 IN. DAMAGE LENGTH: 0.571

G137



R23-17-1

10X

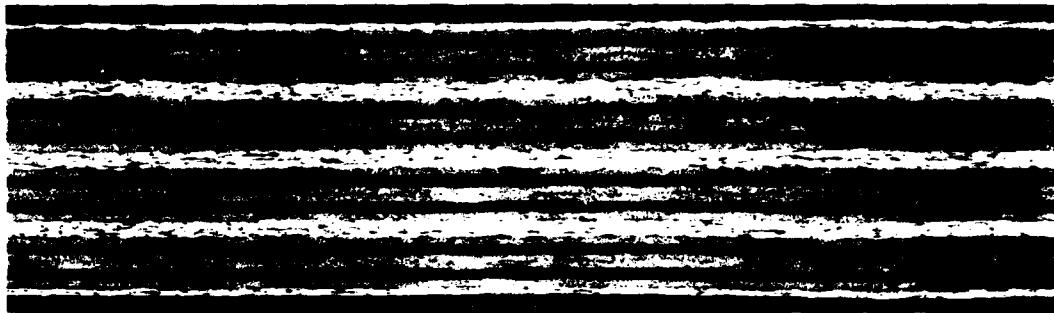


R23-17-2

25X

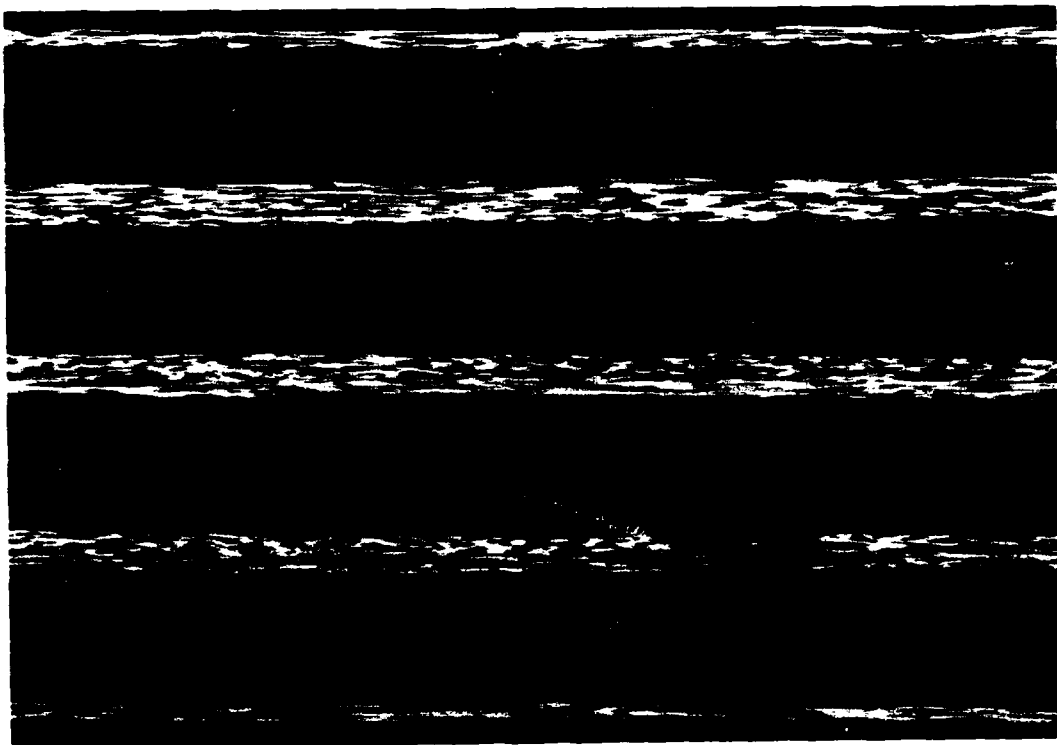
LOCATION: 2.21 IN. DAMAGE LENGTH: 0.396

G138



R23-18-1

10X



R23-18-2

25X

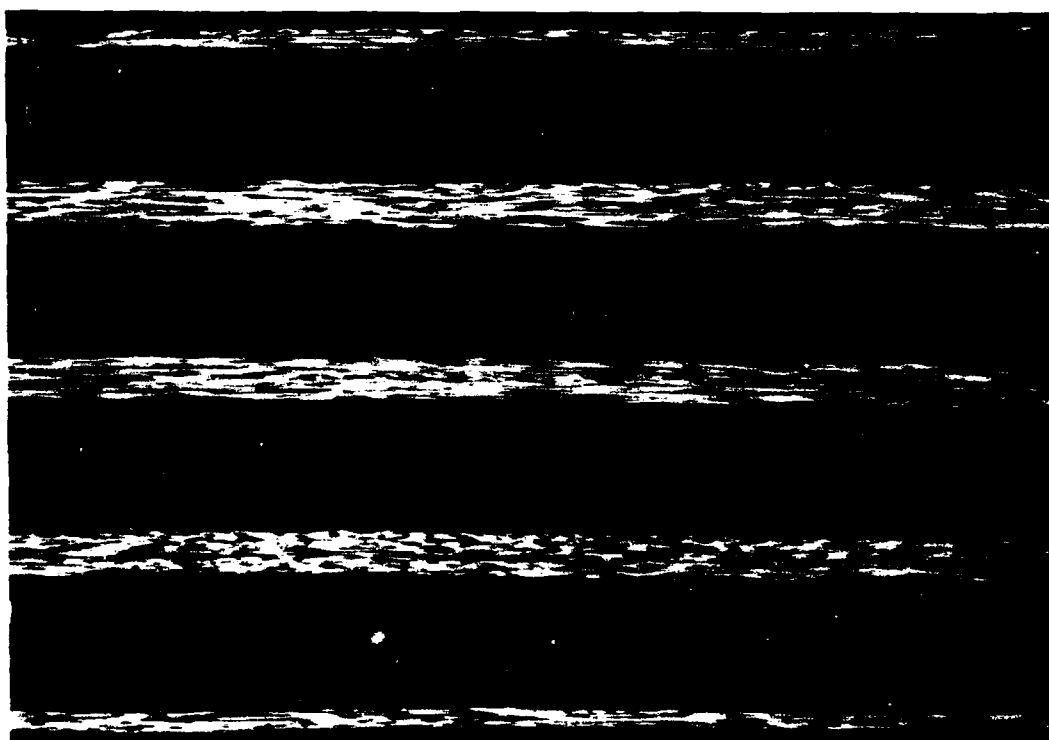
LOCATION: 2.31 in. DAMAGE LENGTH: 0.241

G139



R23-19-1

10X



R23-19-2

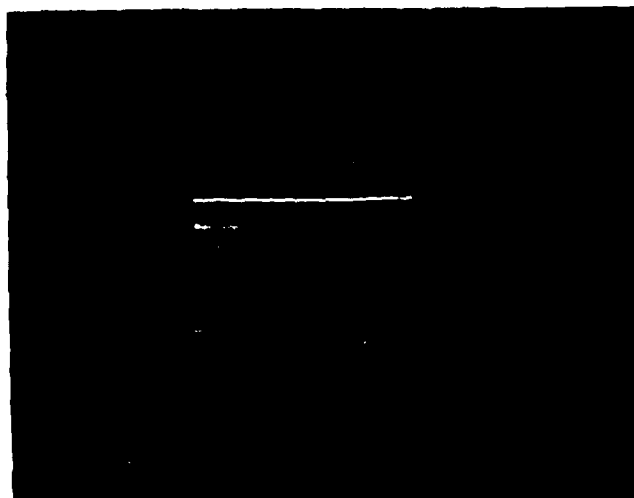
25X

LOCATION: 2.41 IN. DAMAGE LENGTH: NO DAMAGE

G140



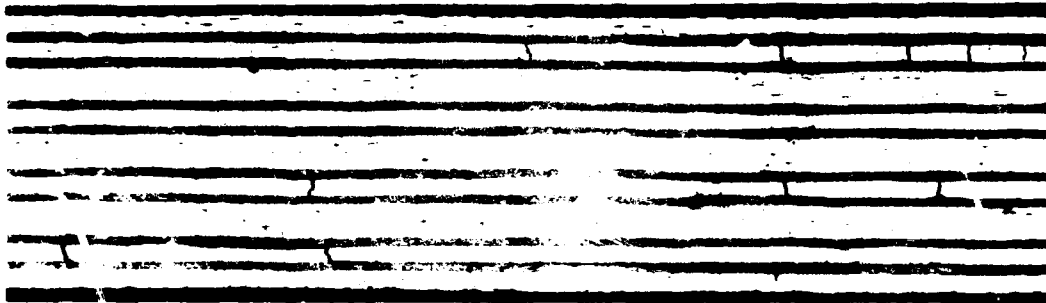
C-SCAN



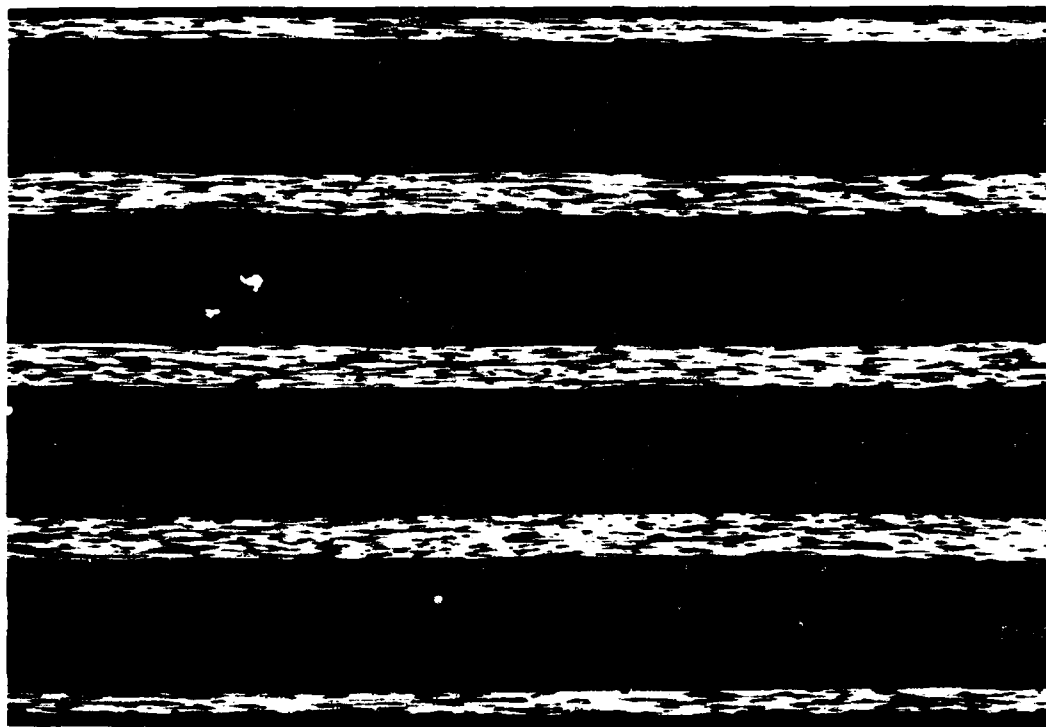
CUMULATIVE E-SCAN

32-PLY SPEC: NB-19 $N_{H1} = 20,000$ CYCLES

G141



10>

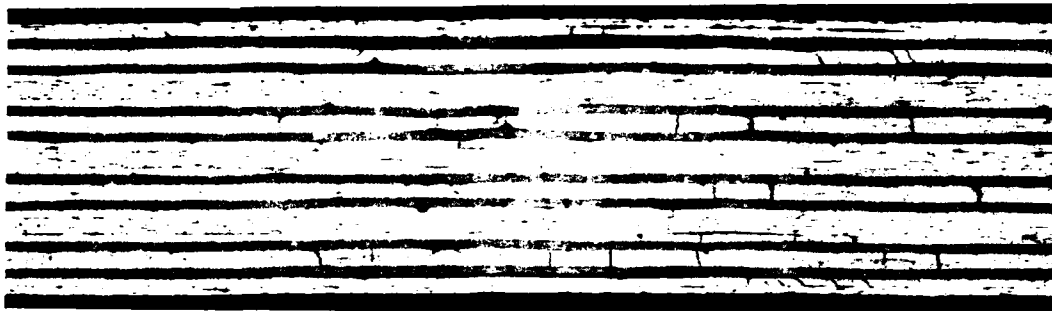


N19-1-2

25X

LOCATION: 0.98 IN. DAMAGE LENGTH: 0.756

6142



N19-2-1

10X



N19-2-2

25X

LOCATION: 1.08 IN. DAMAGE LENGTH: 0.717

G143

LOCATION: 1.18 IN. DAMAGE LENGTH: 0.764



N19-3-1

10X

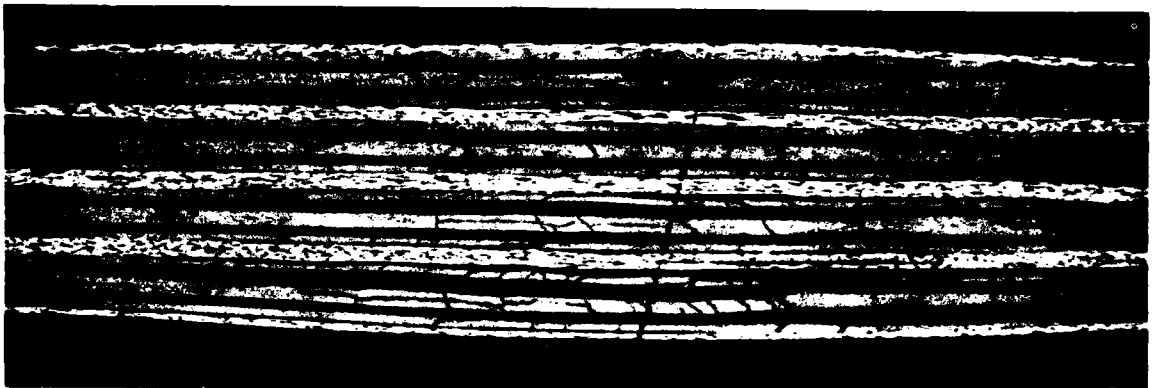


N19-3-2

25X



B-SCAN AT 1.17 IN.
G144



N19-4-1

10X

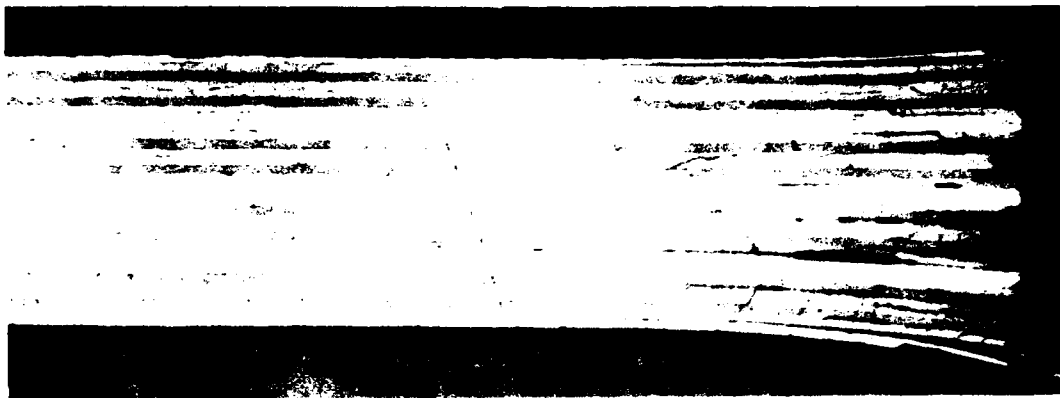


N19-4-2

25X

LOCATION: 1.28 IN. DAMAGE LENGTH: 0.730

G145



N19-5-1A

10Y

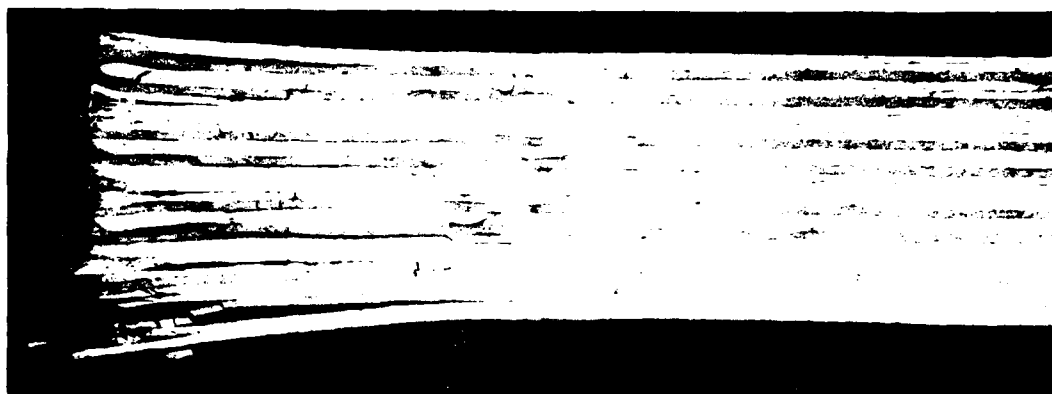


N19-5-2A

25Y

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.833

114



N19-5-1B

10X

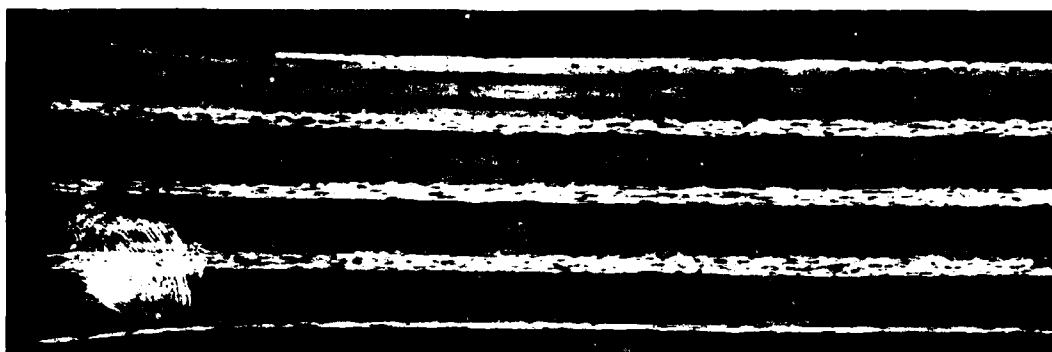


N19-5-2B

25X

LOCATION: 1.38 IN. DAMAGE LENGTH: 0.833

G147



N19-6-1A

10X



N19-6-2A

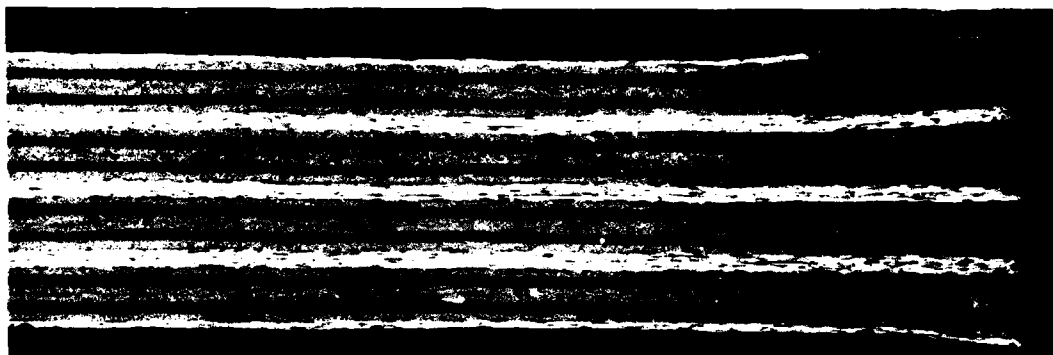
25X



B-SCAN AT CENTER

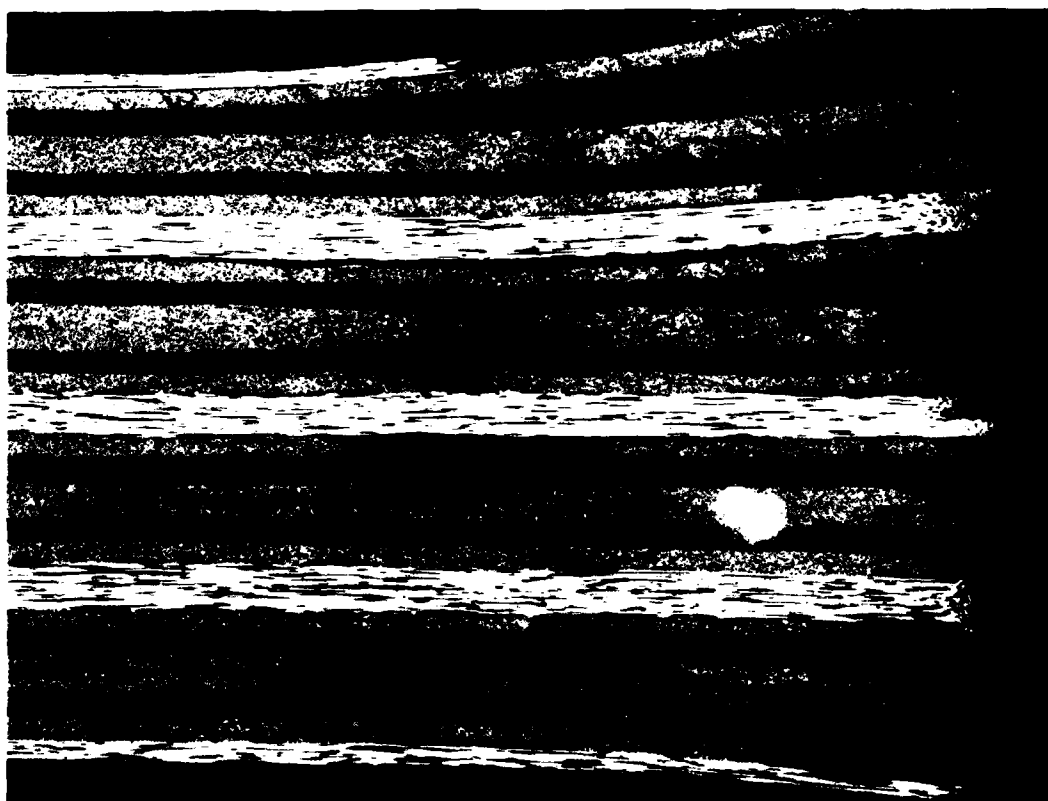
LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918

G148



N19-6-1B

10X



N19-6-2B

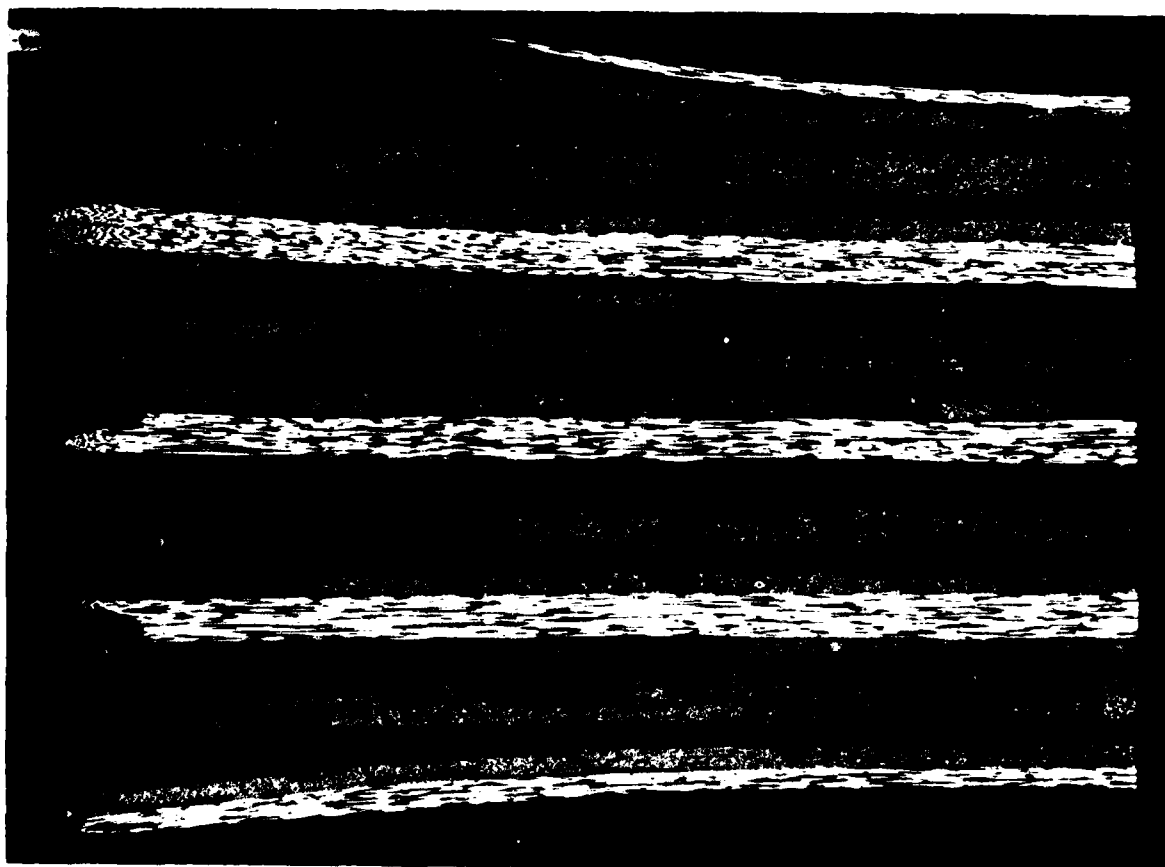
25X

LOCATION: 1.48 IN. DAMAGE LENGTH: 0.918



N19-7-1A

10Y

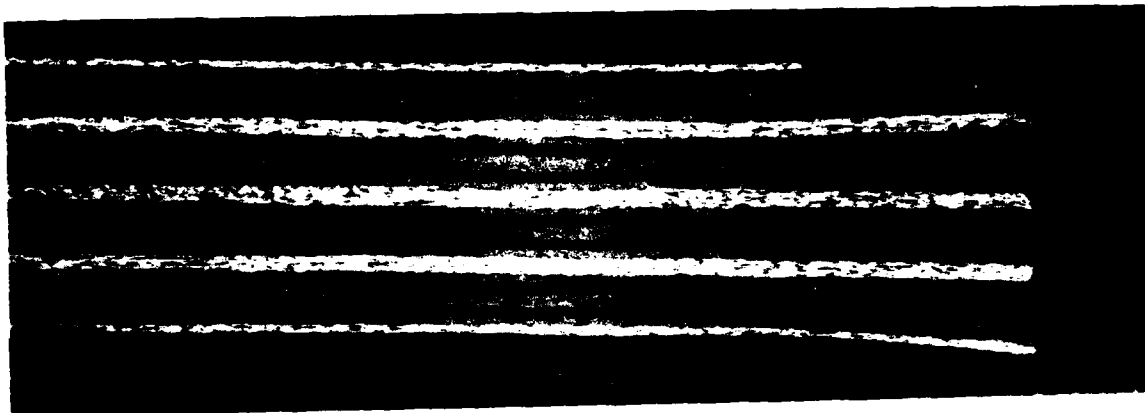


N19-7-2A

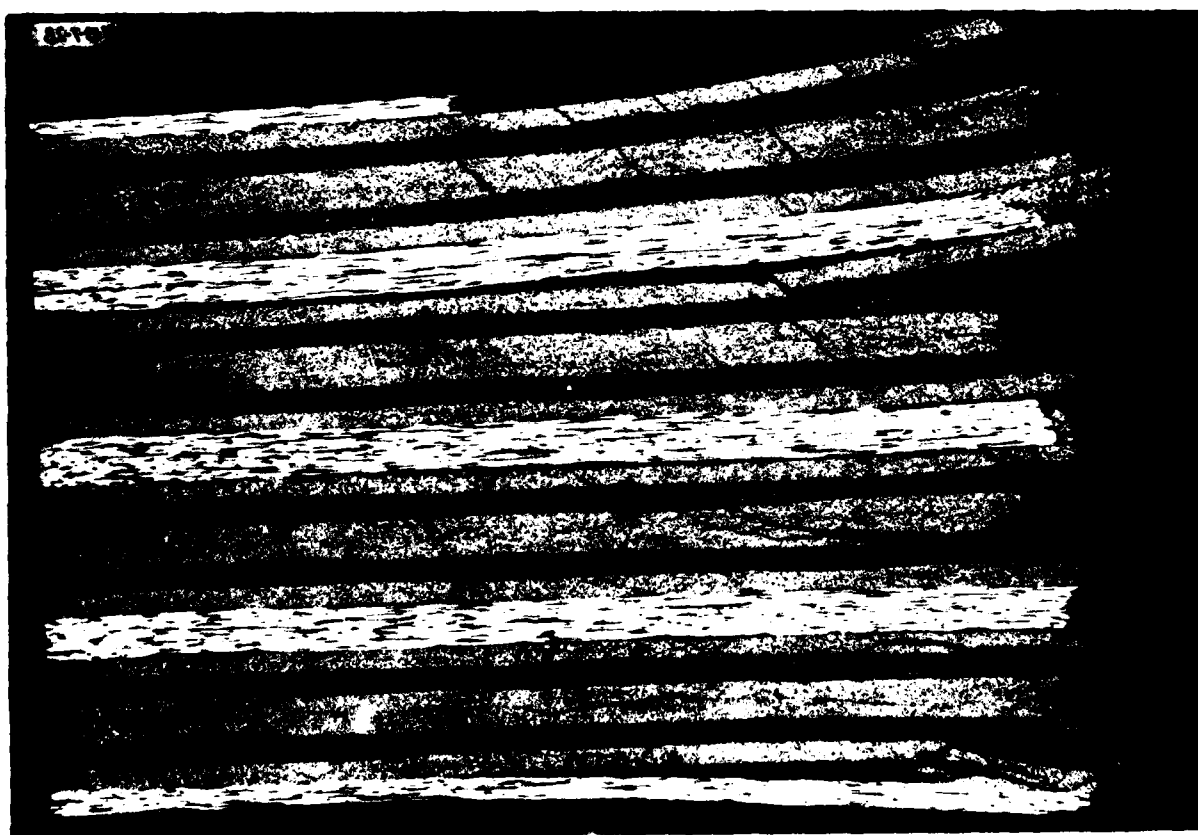
25Y

LOCATION: 1.58 in. DAMAGE LENGTH: 2.928

G150



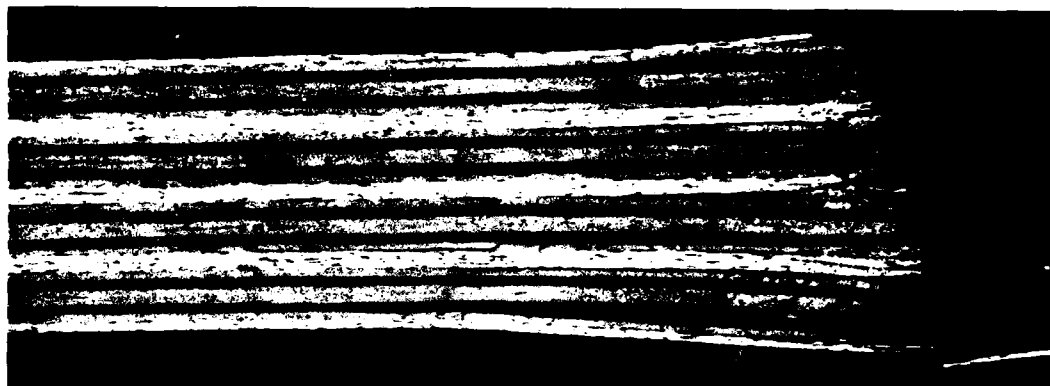
N19-7-1B



N19-7-2B

LOCATION: 1.58 IN. DAMAGE LENGTH: 9.628

G151



N10-8-1A

10X



N10-8-2A

25X

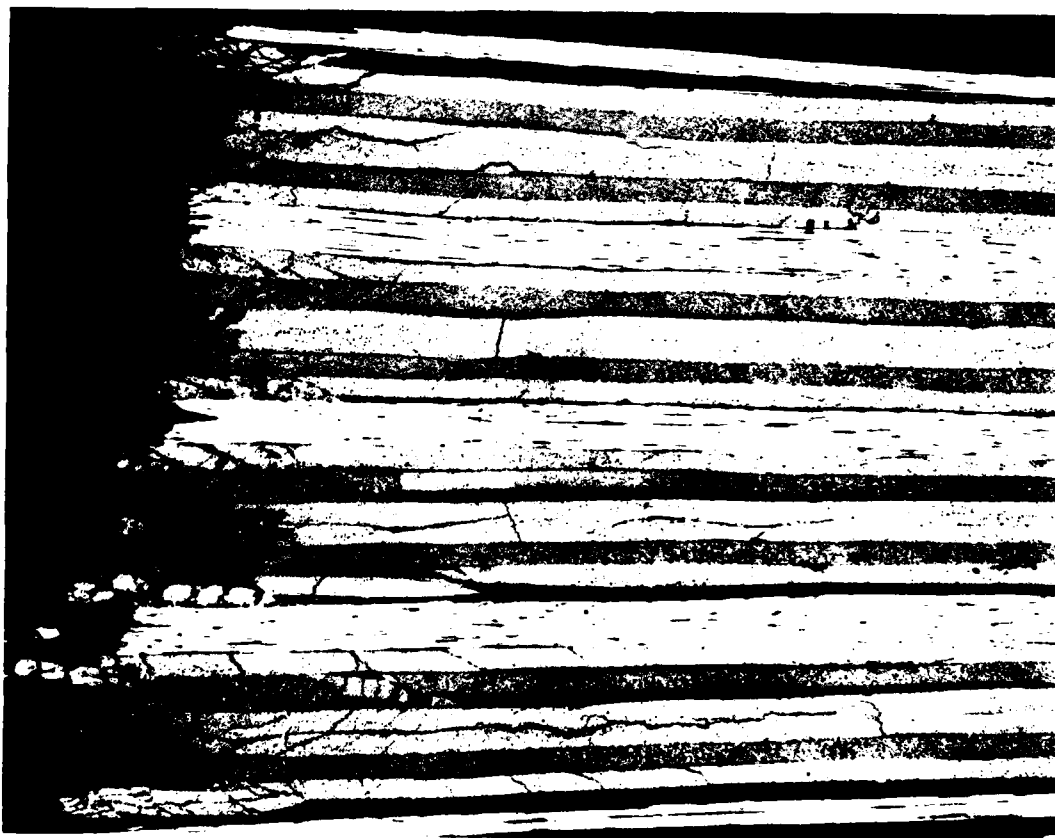
LOCATION: 1.68 IN. DAMAGE LENGTH: 0.933

G152



N19-8-1B

10X



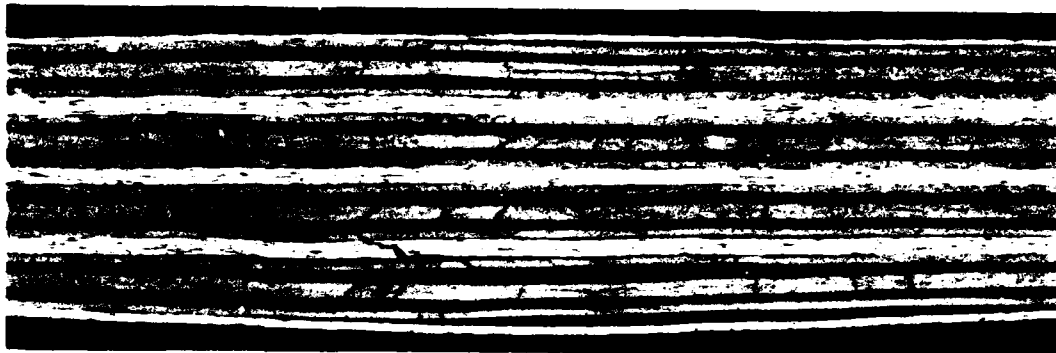
N19-8-2B

25X

LOCATION: 1.68 IN. DAMAGE LENGTH: 0.935

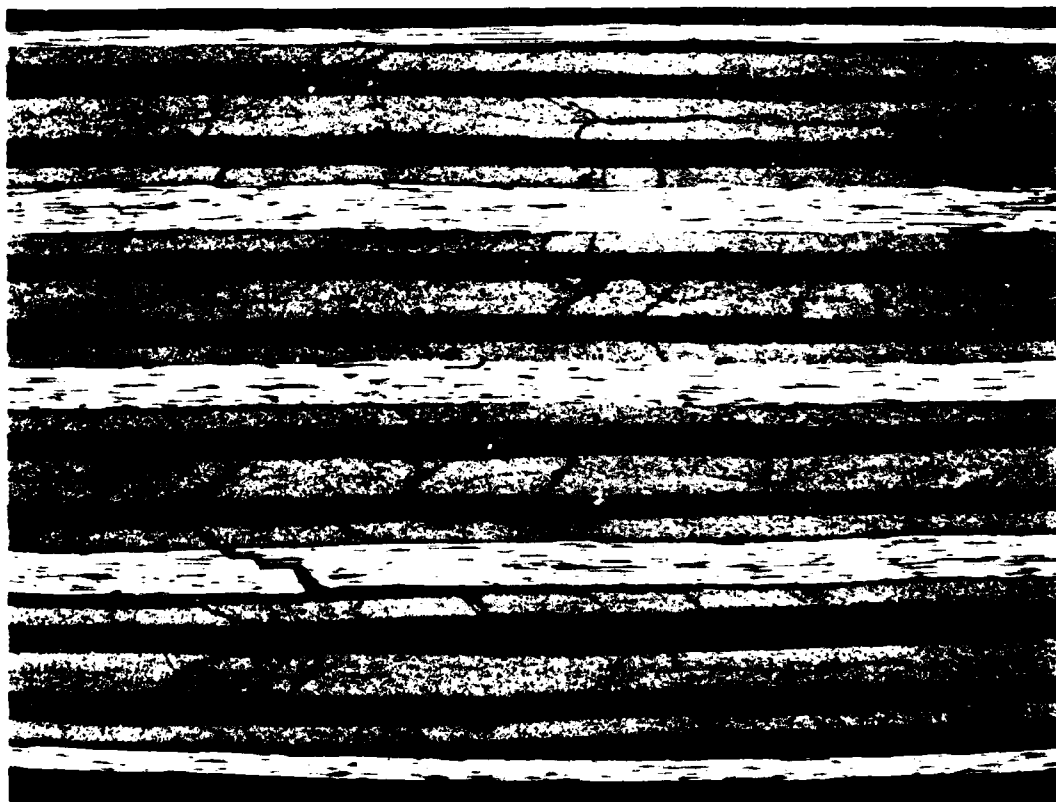
G153

LOCATION: 1.78 IN. DAMAGE LENGTH: 0.888



N19-9-1

10X



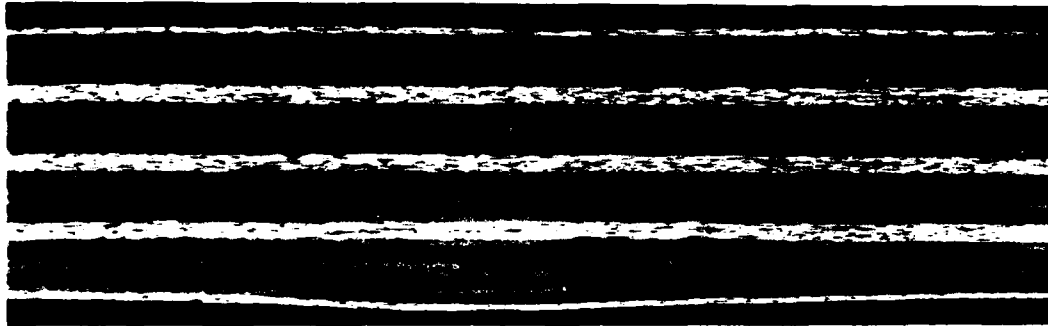
N19-9-2

25X



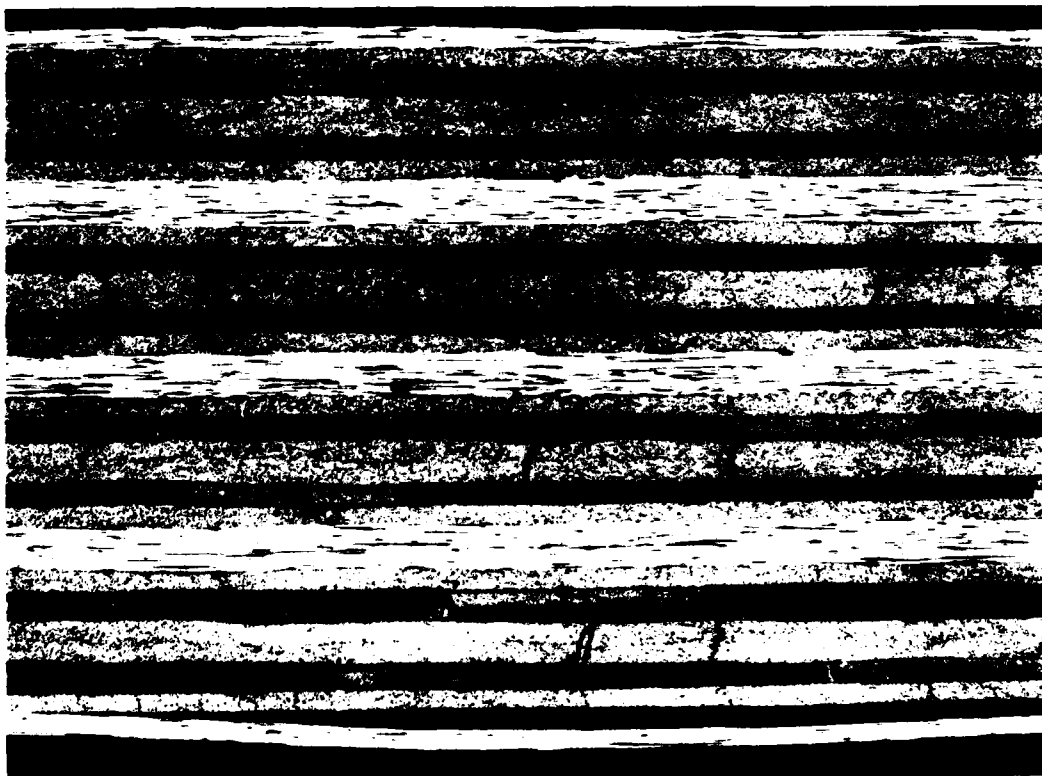
B-SCAN AT 1.70 IN.

G154



N19-10-1

10X

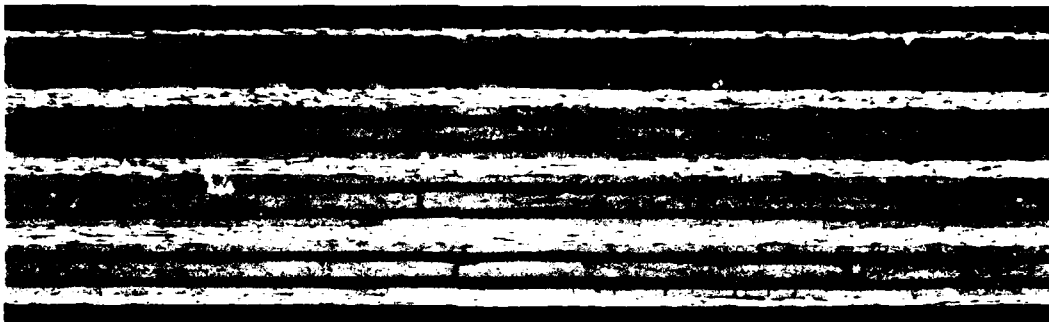


N19-10-2

25X

LOCATION: 1.88 IN. DAMAGE LENGTH: 0.630

G155



N19-11-1

10X



N19-11-2

25X

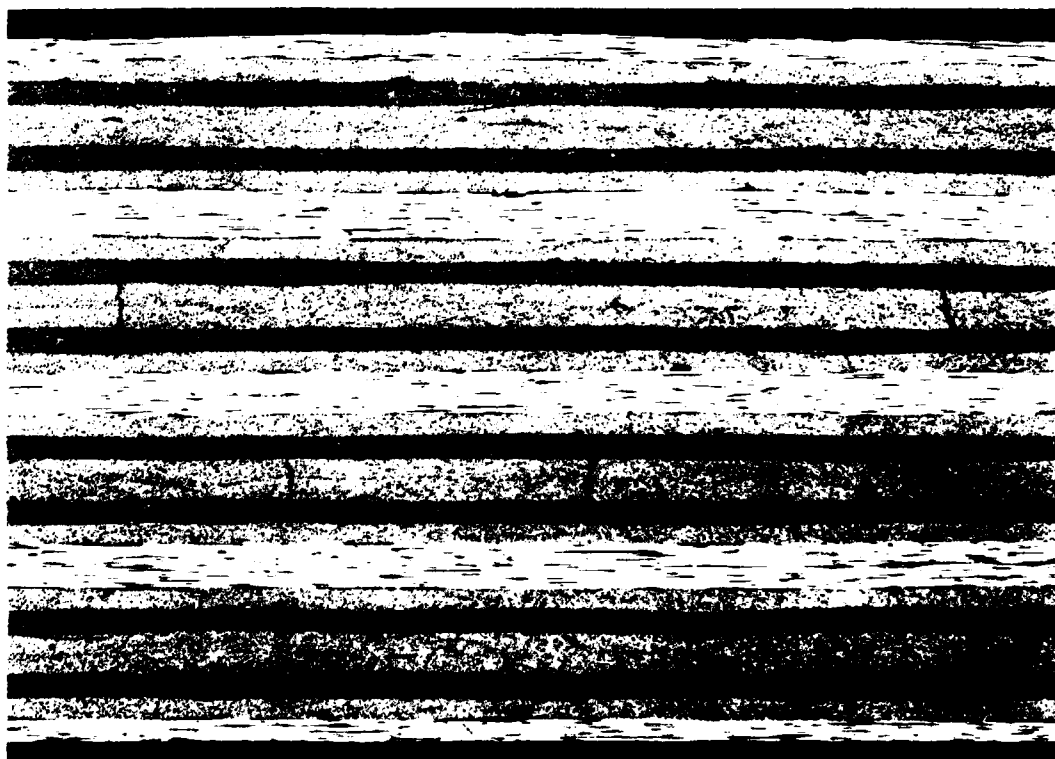
LOCATION: 1.98 IN. DAMAGE LENGTH: 0.011

G156



P19-12-1

10X



P19-12-2

25X

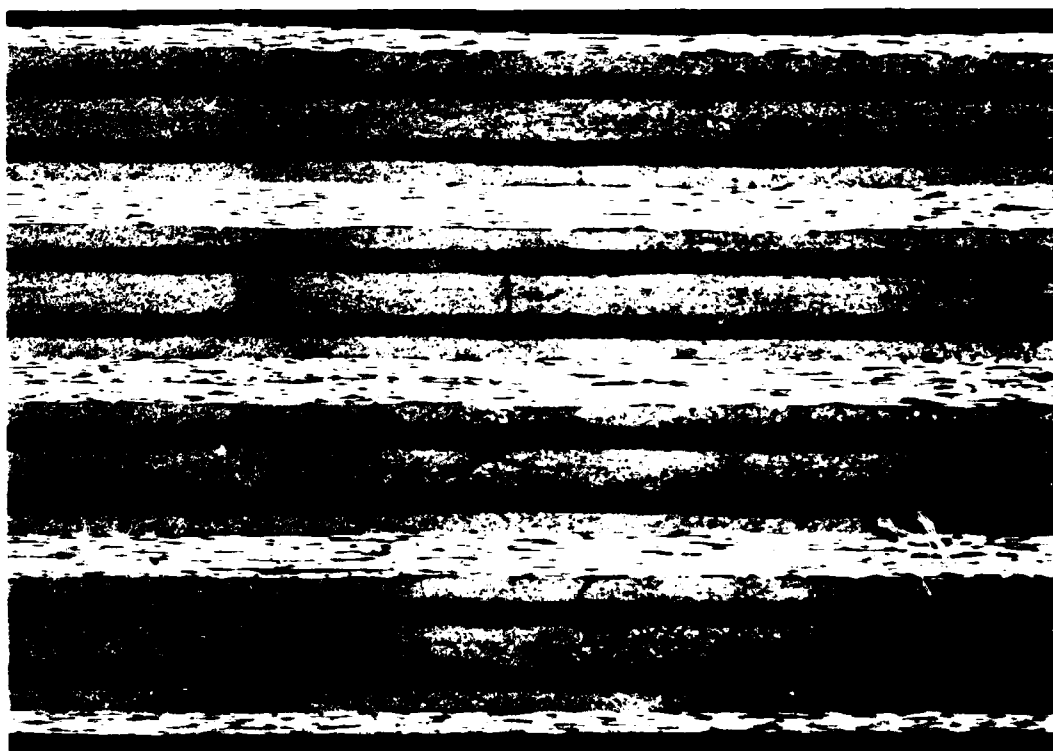
LOCATION: 2.08 IN. DAMAGE LENGTH: 0.562

G157



N19-13-1

10X

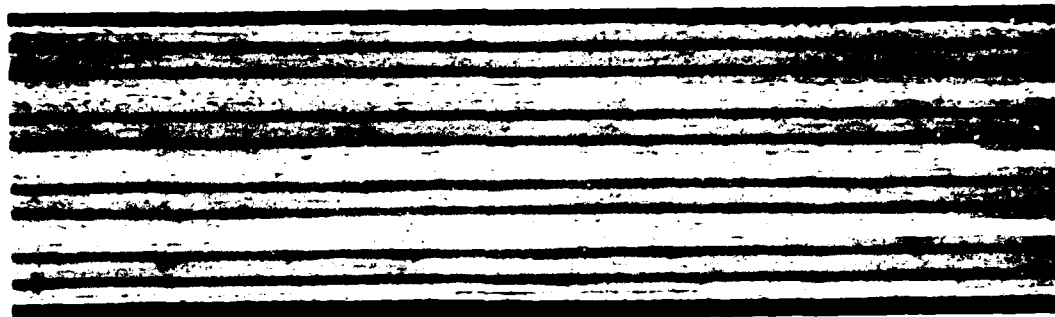


N19-13-2

25X

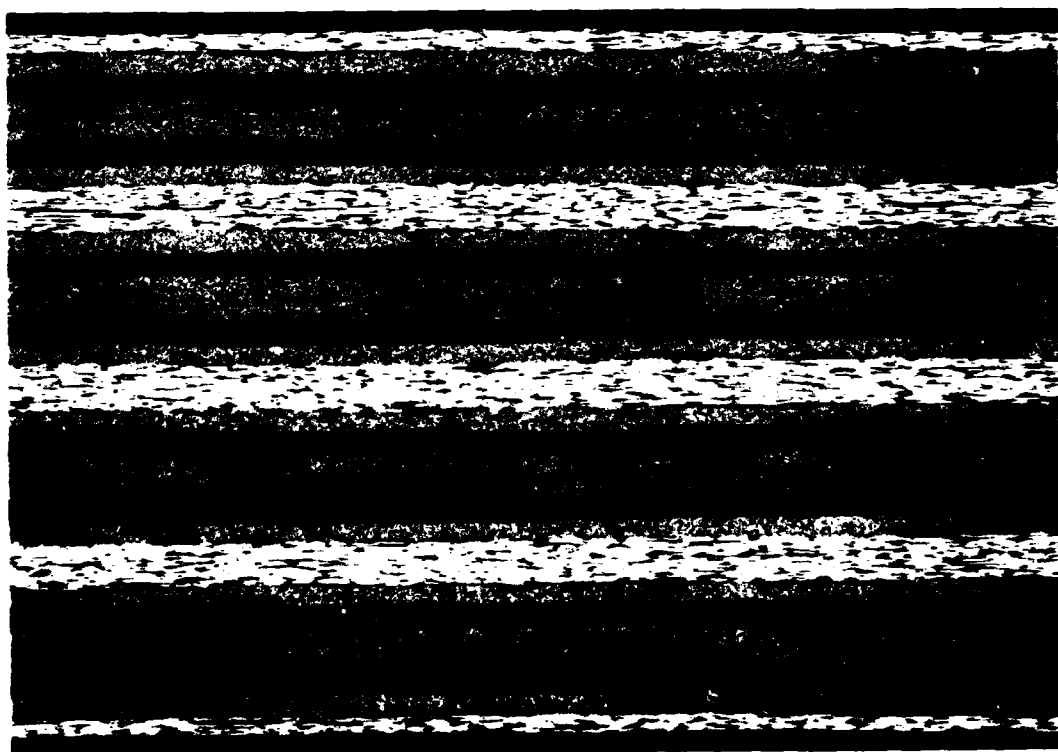
LOCATION: 2.18 IN. DAMAGE LENGTH: 0.539

G158



N19-14-1

10X

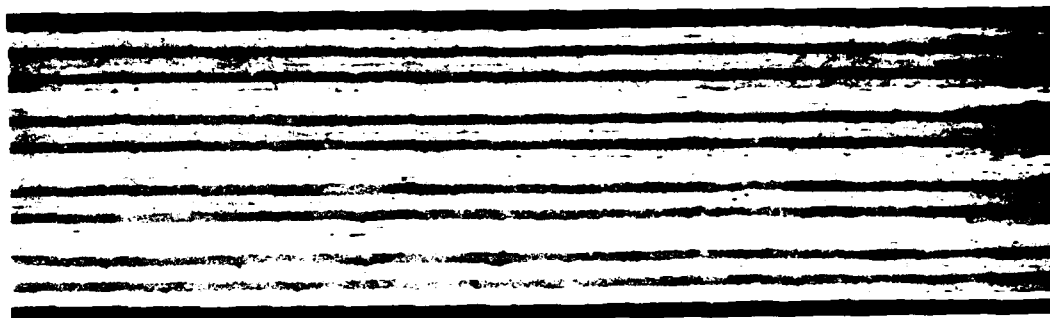


N19-14-2

25X

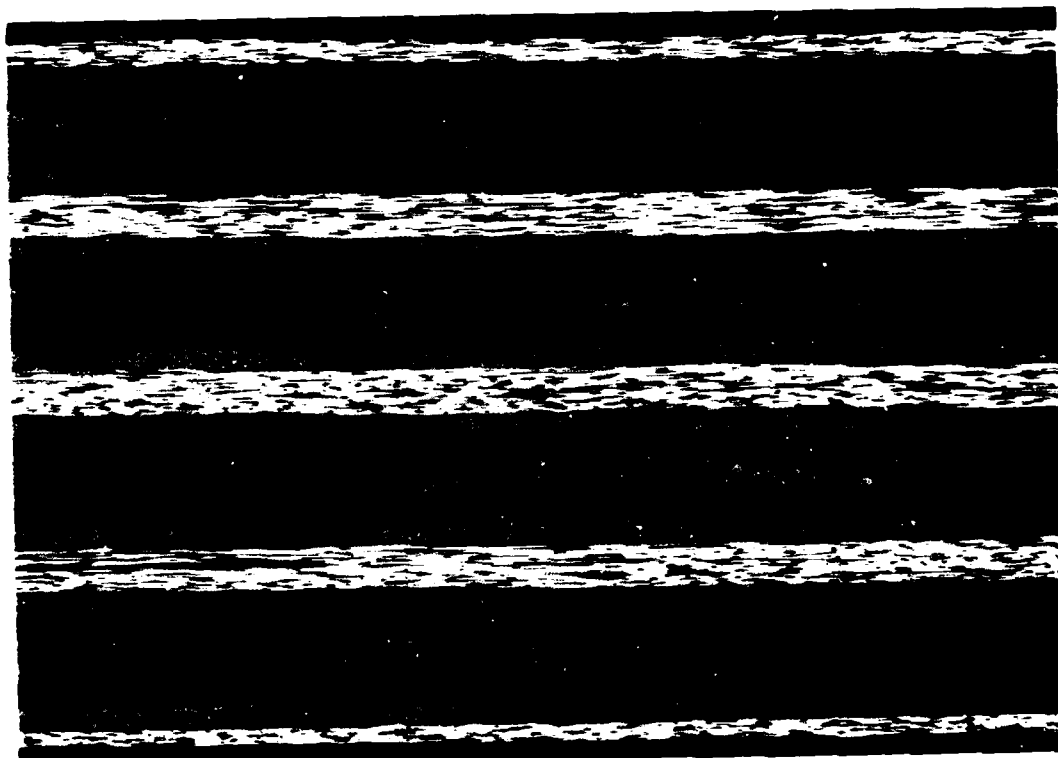
LOCATION: 2.28 IN. DAMAGE LENGTH: 0.214

G159



N19-15-1

10X

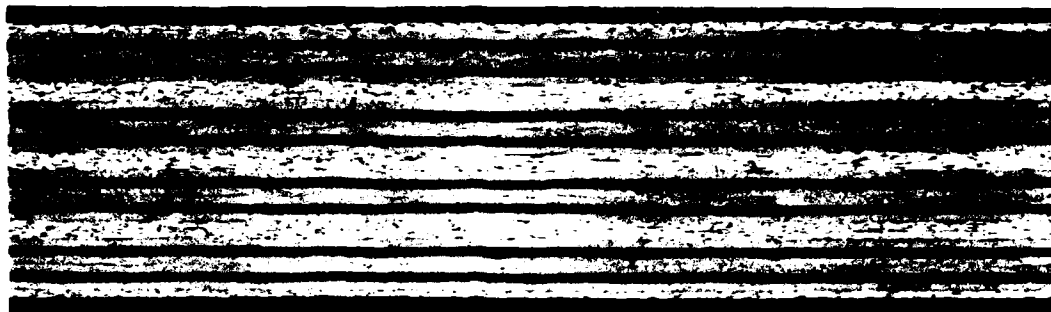


N19-15-2

25X

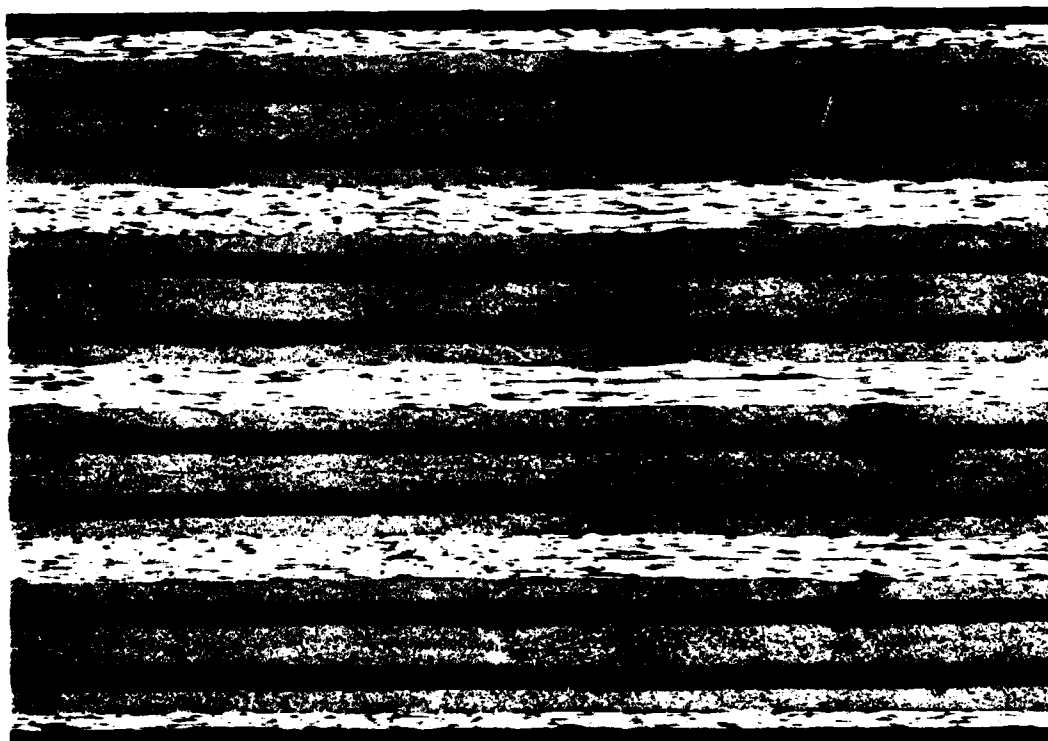
LOCATION: 2.38 IN. DAMAGE LENGTH: 0.078

G160



N19-16-1

10X

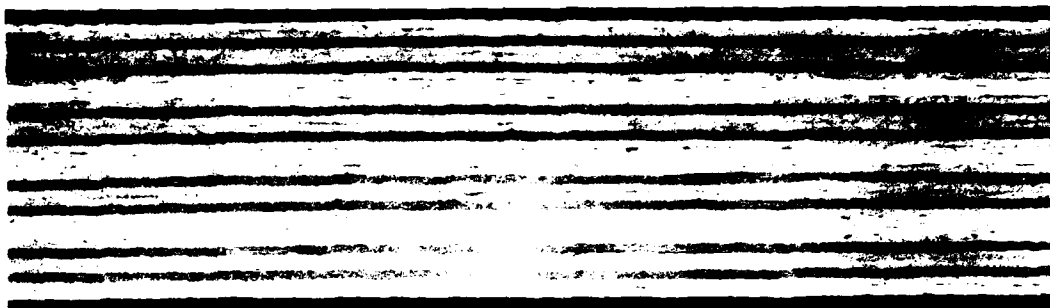


N19-16-2

25X

LOCATION: 2.48 IN. DAMAGE LENGTH: 0.122

G161



N19-17-1

10X

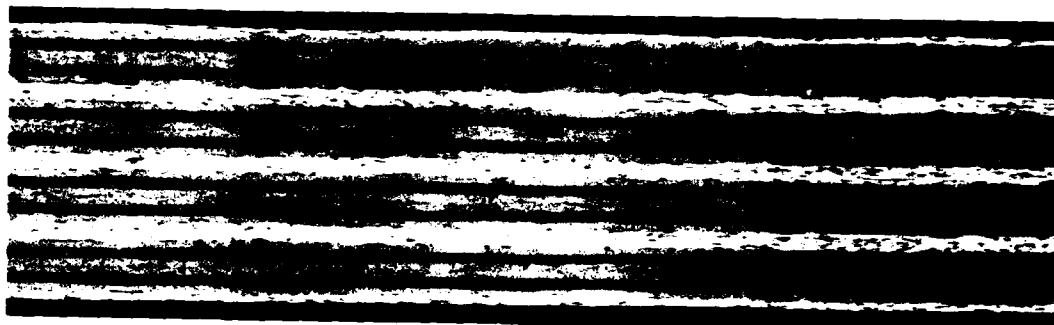


N19-17-2

25X

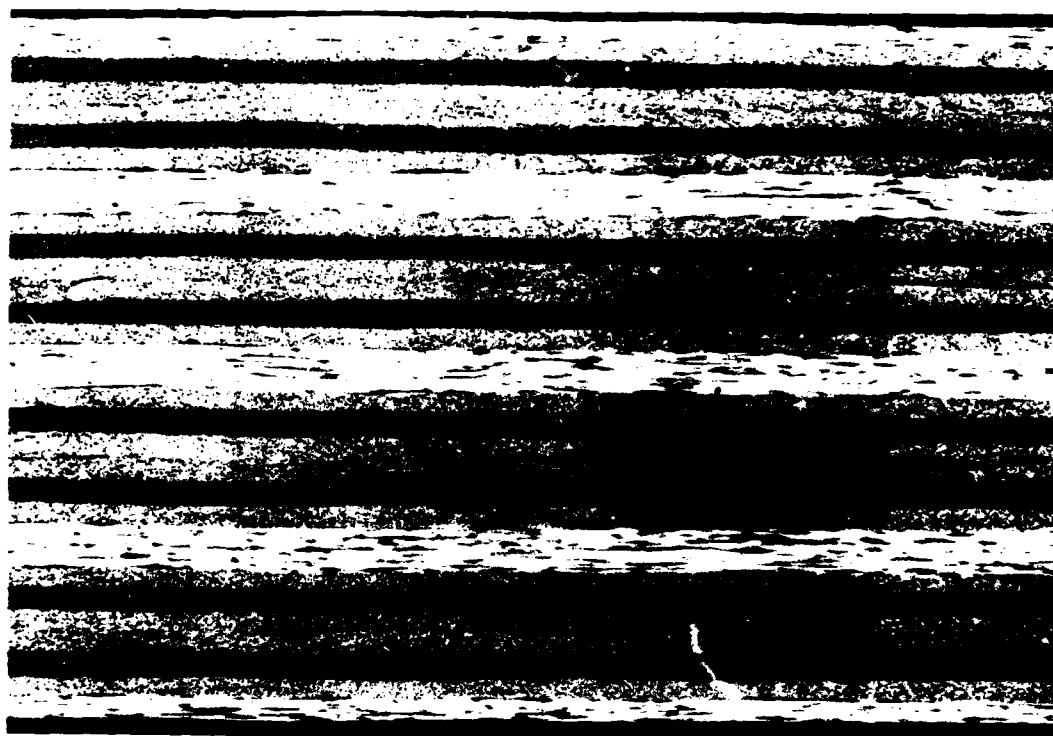
LOCATION: 2.58 IN. DAMAGE LENGTH. 0.108

G162



N19-18-1

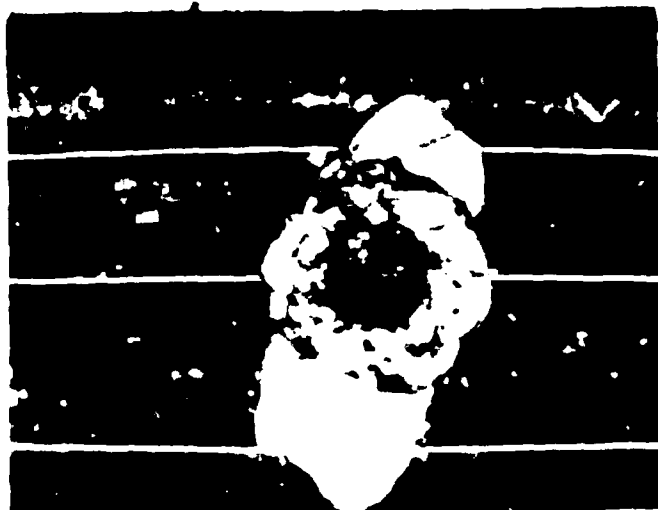
10X



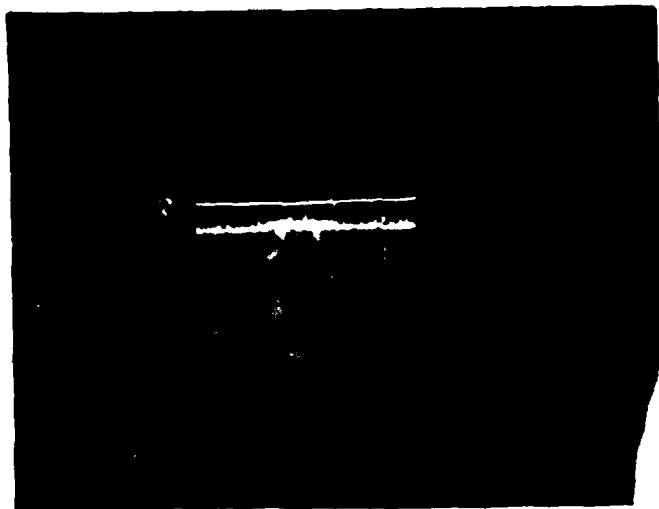
N19-18-2

25X

LOCATION: 2.63 IN. DAMAGE LENGTH: ONE TRANS CRACK THRU TWO PLYS



C-SCAN



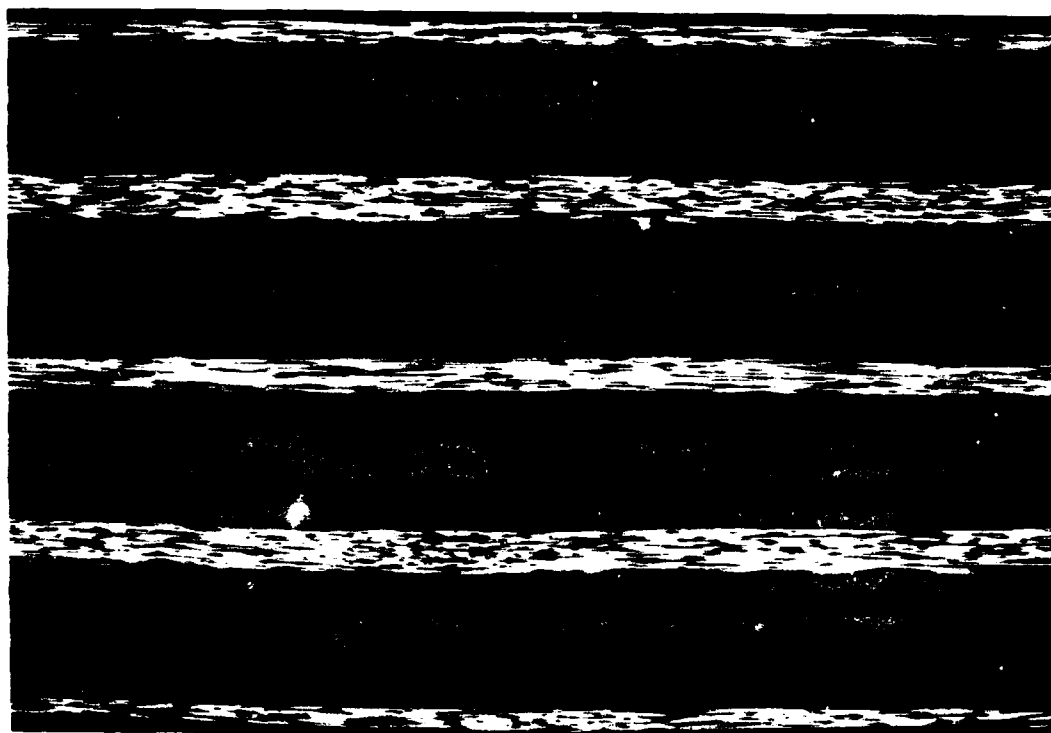
CUMULATIVE B-SCAN

32-PLY SPEC: JC-30 N₅ = 28,000 CYCLES



J30-1-1

10X



J30-1-2

25X

LOCATION: 0.84 IN. DAMAGE LENGTH: 0.217

G165



J30-2-1

10X



J30-2-2

25X



B-SCAN AT 0.98 IN.

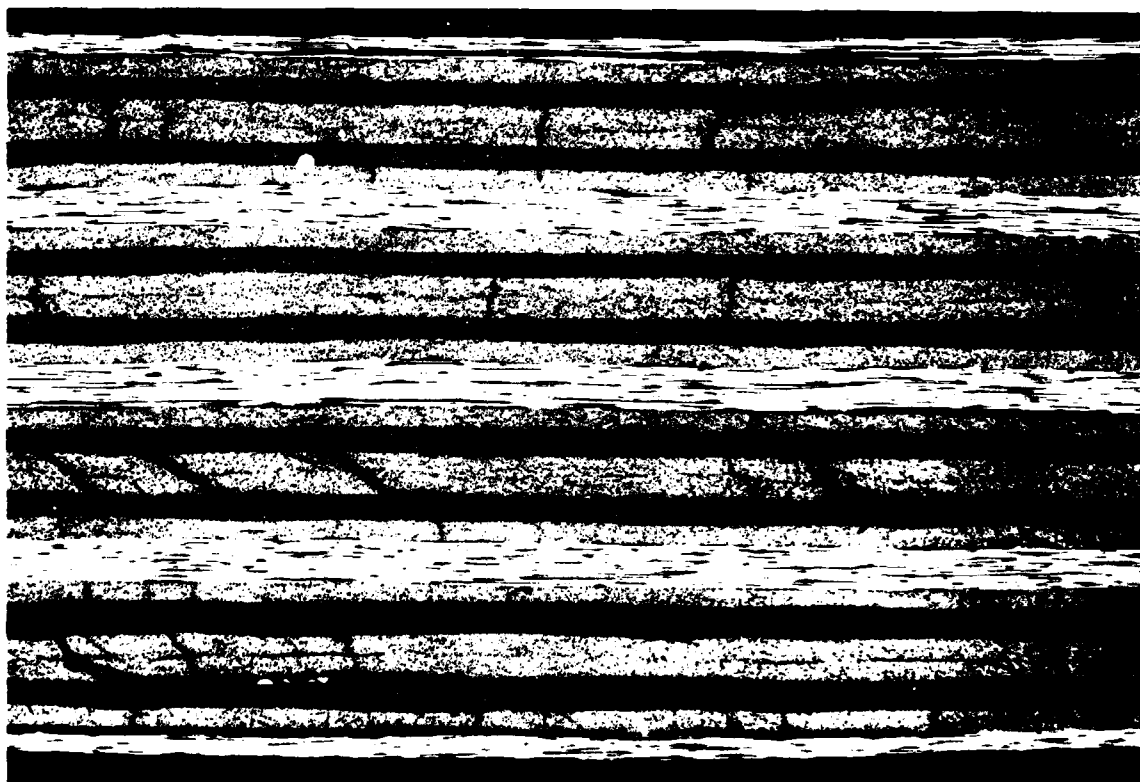
LOCATION: 0.94 IN. DAMAGE LENGTH: 0.657

G166



J30-3-1

10X



J30-3-2

25 X

LOCATION: 1.04 IN. DAMAGE LENGTH: 0.727

G167



J30-4-1

10 X



J30-4-2

25X

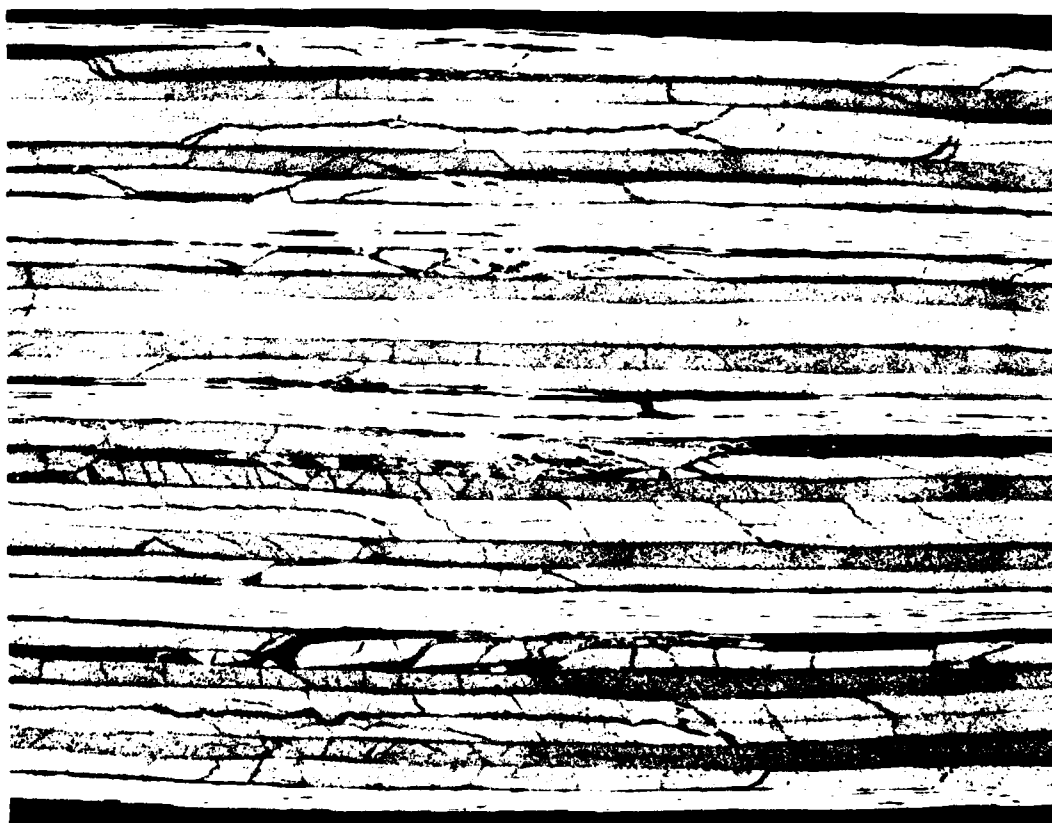
LOCATION: 1.14 IN. DAMAGE LENGTH: 0.746

G168



J30-5-1

10X



J30-5-2

25X

LOCATION: 1.24 in. DAMAGE LENGTH: 0.764

G169



J30-6-1A

10X

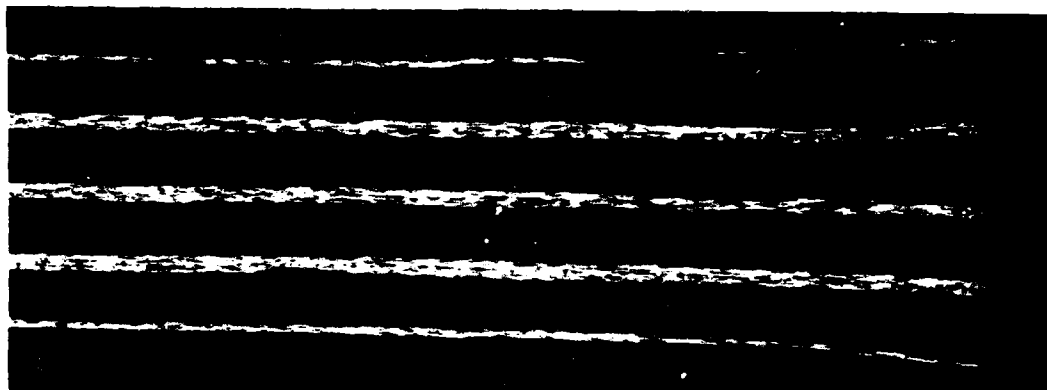


J30-6-1A

25X

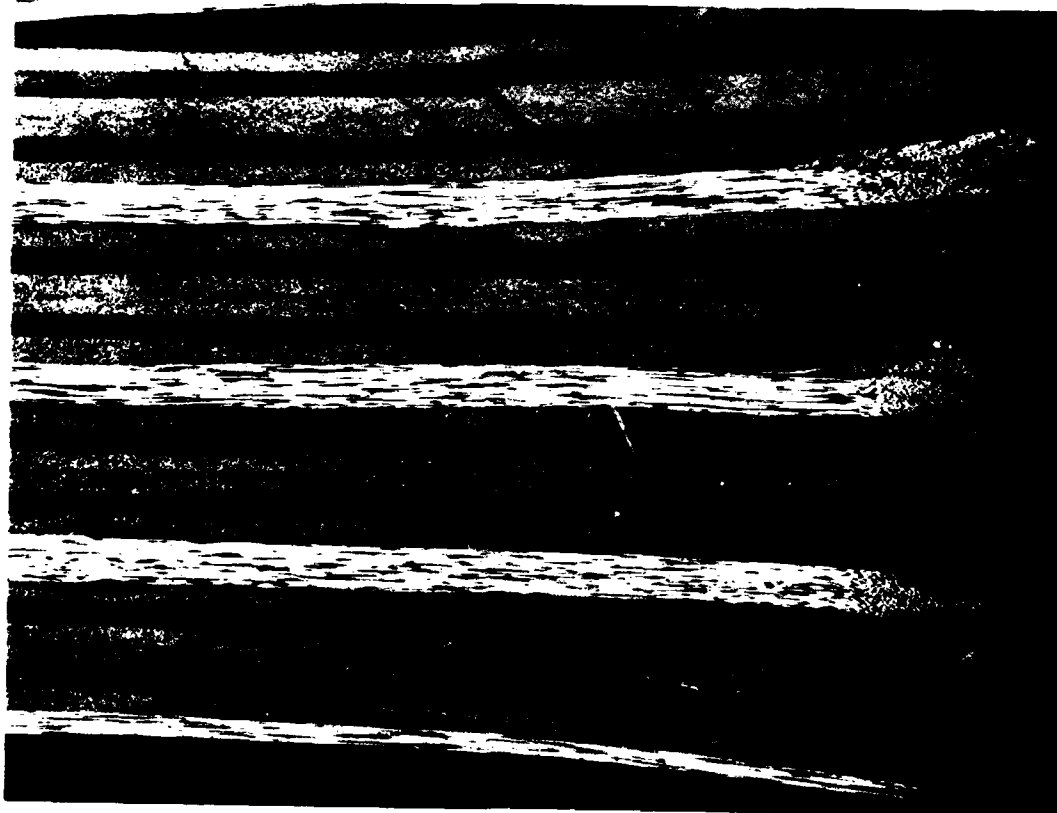
LOCATION: 1.34 IN. DAMAGE LENGTH: 0.967

G170



J30-6-1B

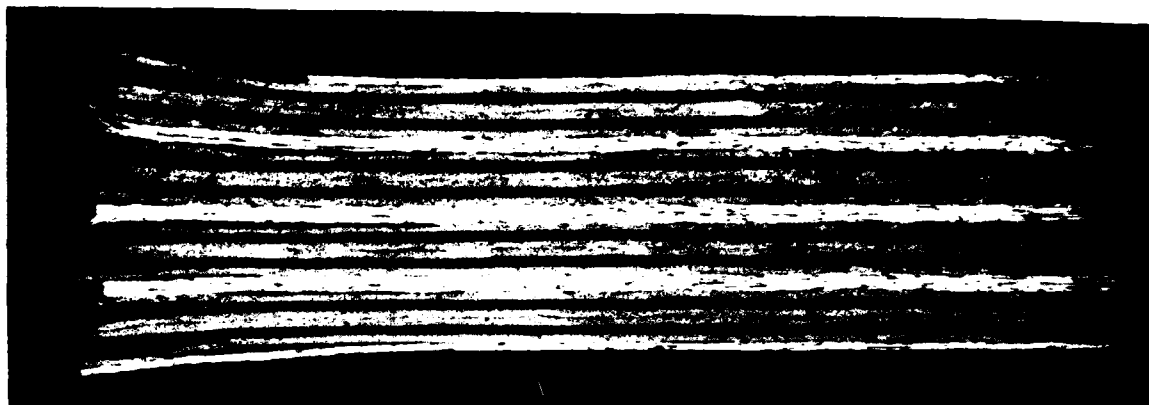
10X



J30-6-2B

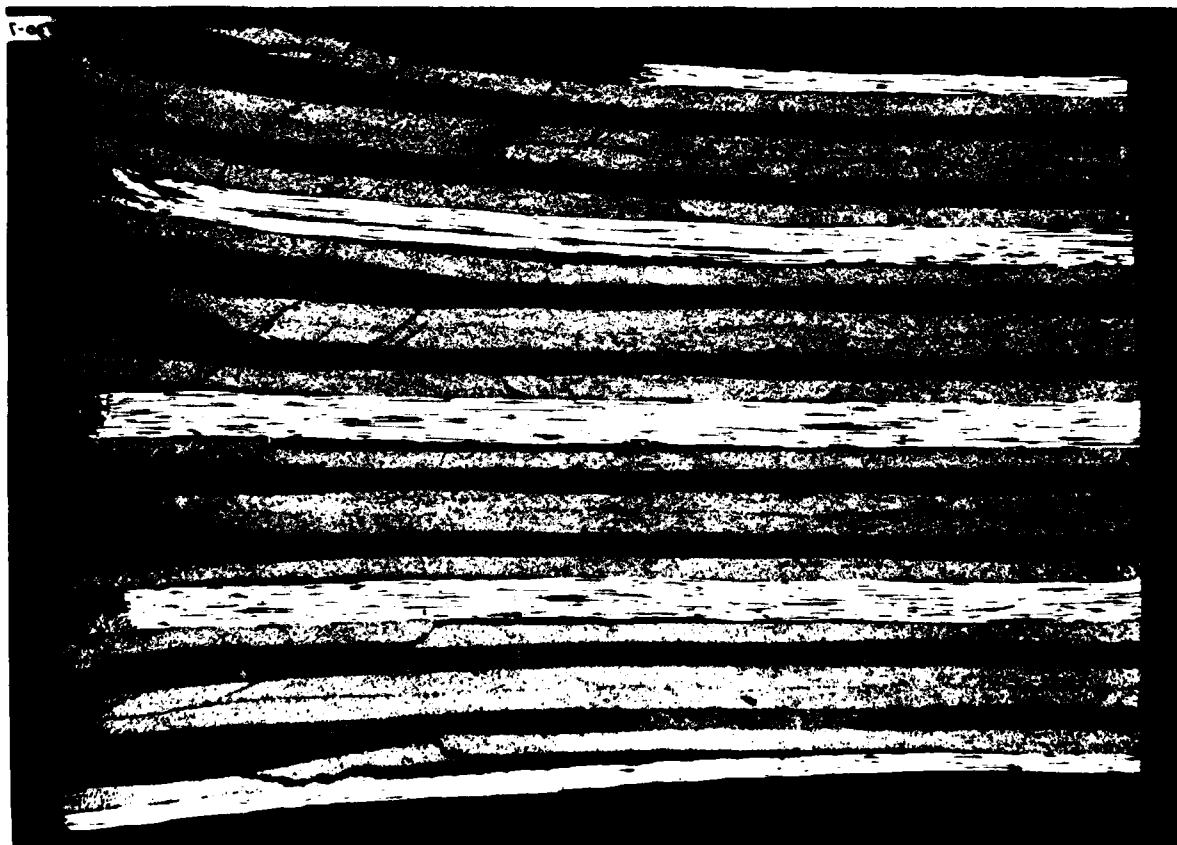
25X

LOCATION: 1.34 IN. DAMAGE LENGTH: 0.967



J30-7-1A

10Y

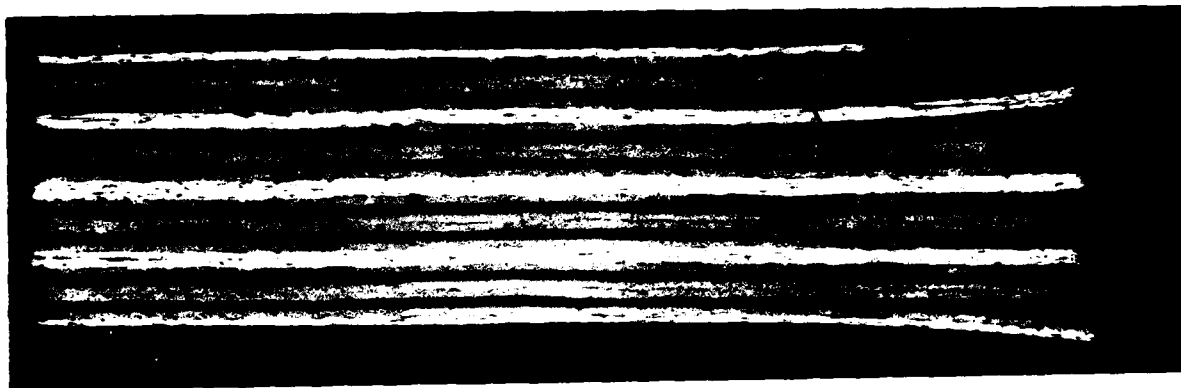


J30-7-01

25Y

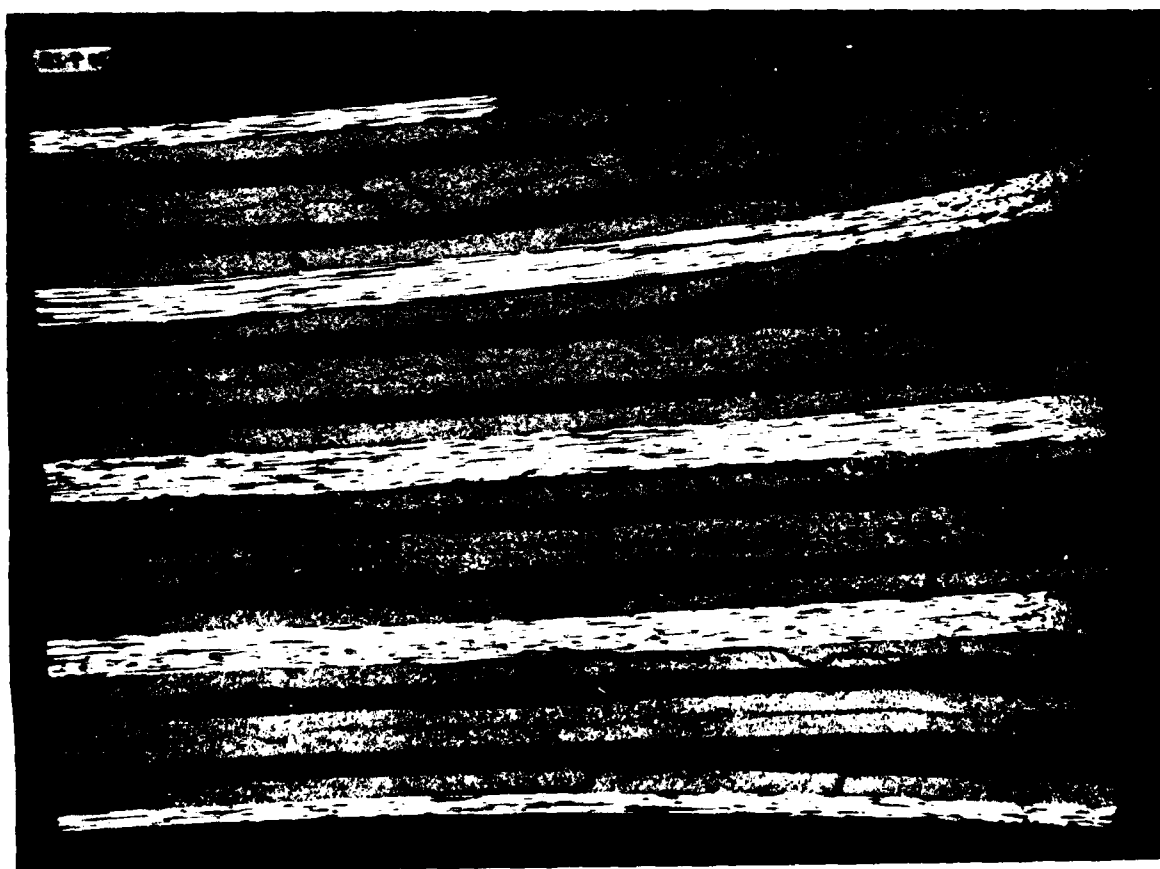
LOCATION: 1.05 IN. DAMAGE LENGTH: 1.102

0172



J30-7-1B

10X

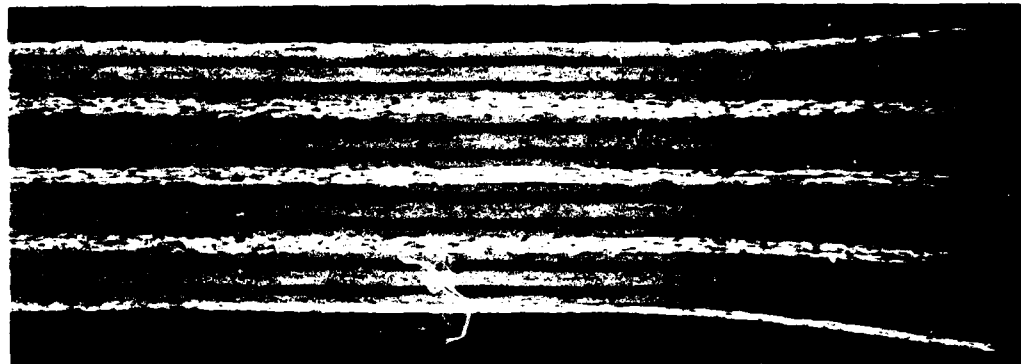


J30-7-2P

25X

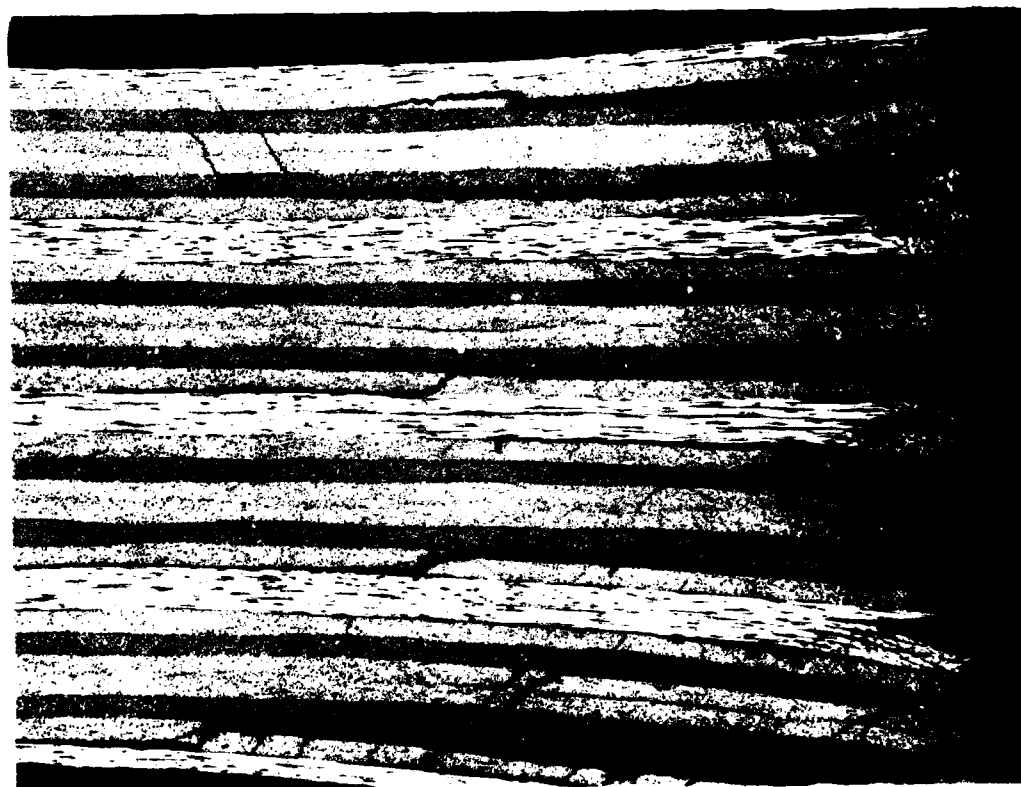
LOCATION: 1.05 IN. DAMAGE LENGTH: 1.192

G173



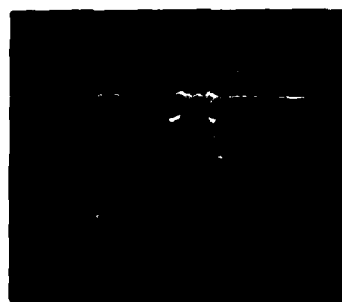
J30-8-1A

10X



J30-8-2A

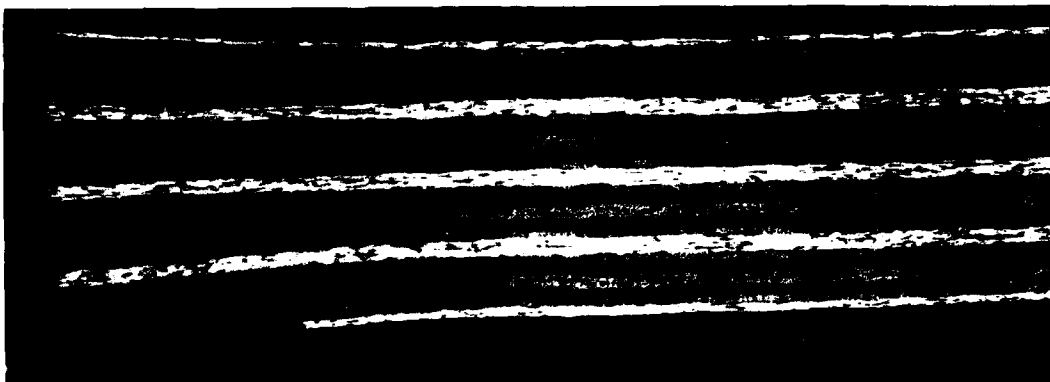
25X



B-SCAN AT CENTER

LOCATION: 1.54 IN. DAMAGE LENGTH: 0.850

G174



J30-8-1B

10X

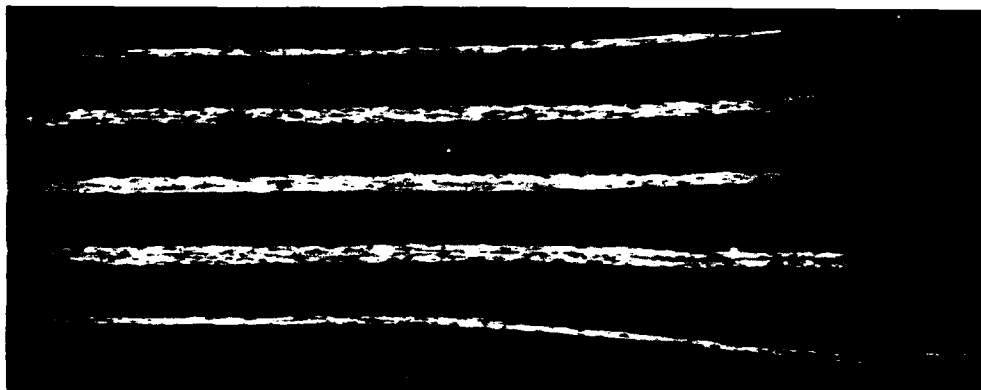


J30-8-2P

25 X

LOCATION: 1.54 IN. DAMAGE LENGTH: 0.850

G175



J30-9-1A

10X

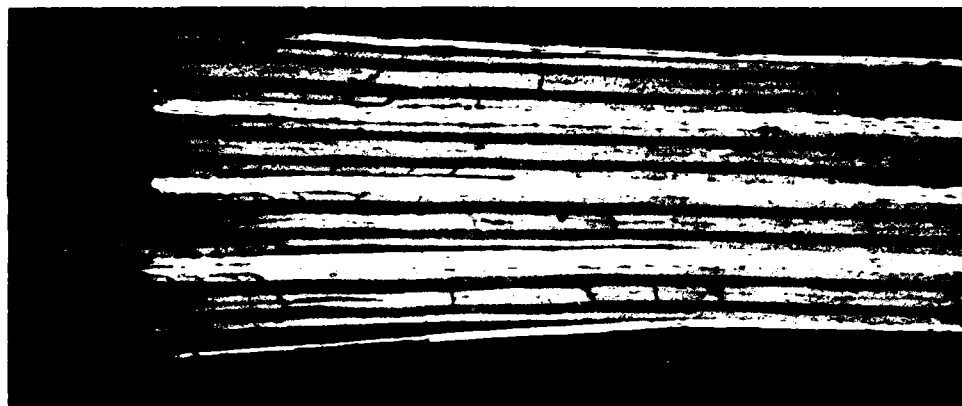


J30-9-2A

25X

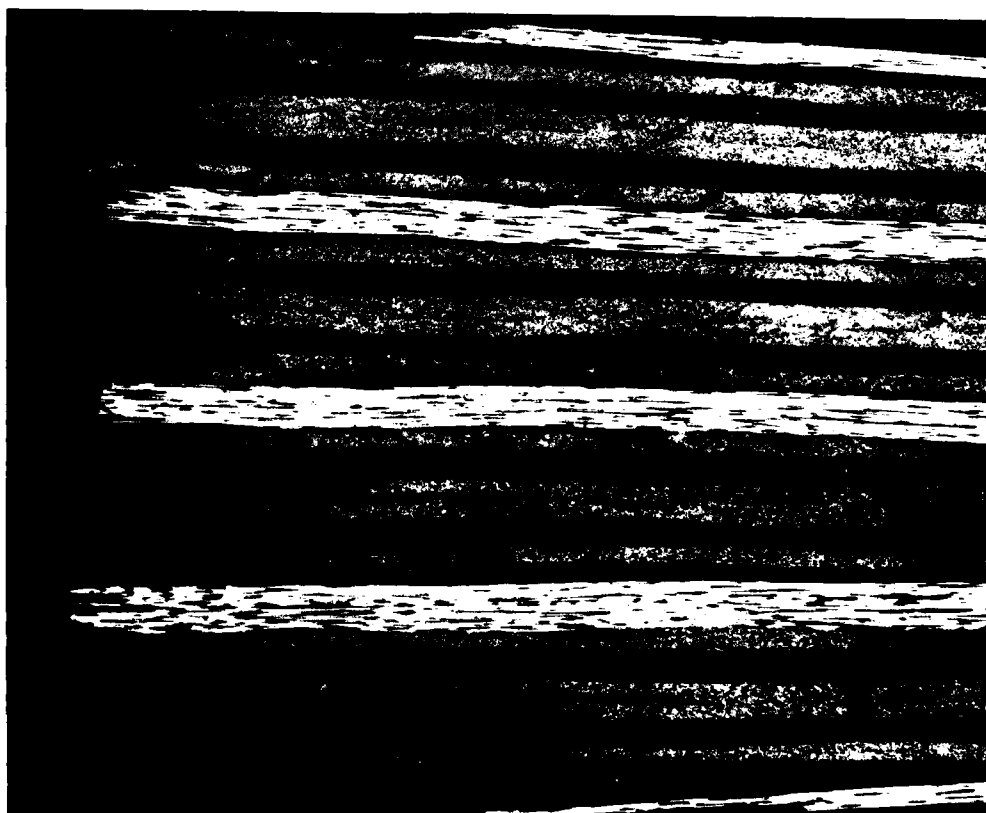
LOCATION: 1.64 IN. DAMAGE LENGTH 0.843

G176



J30-9-1E

10X

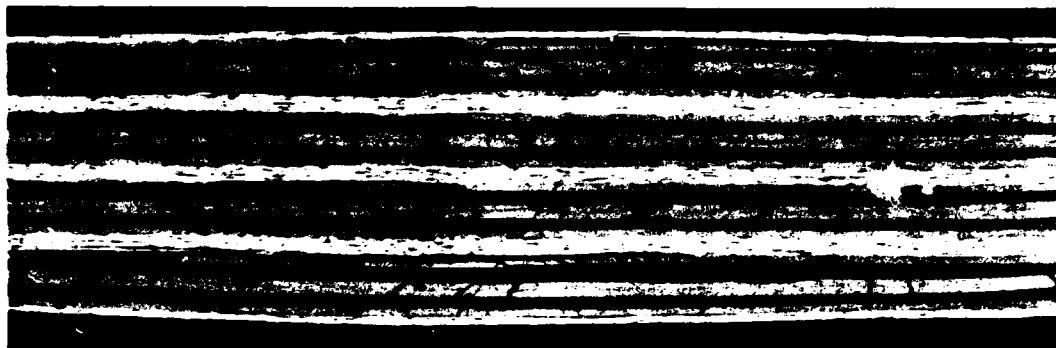


J30-9-2E

25X

LOCATION: 1.64 IN. DAMAGE LENGTH 0.847

G177



J30-10-1

10X



J30-10-2

25X

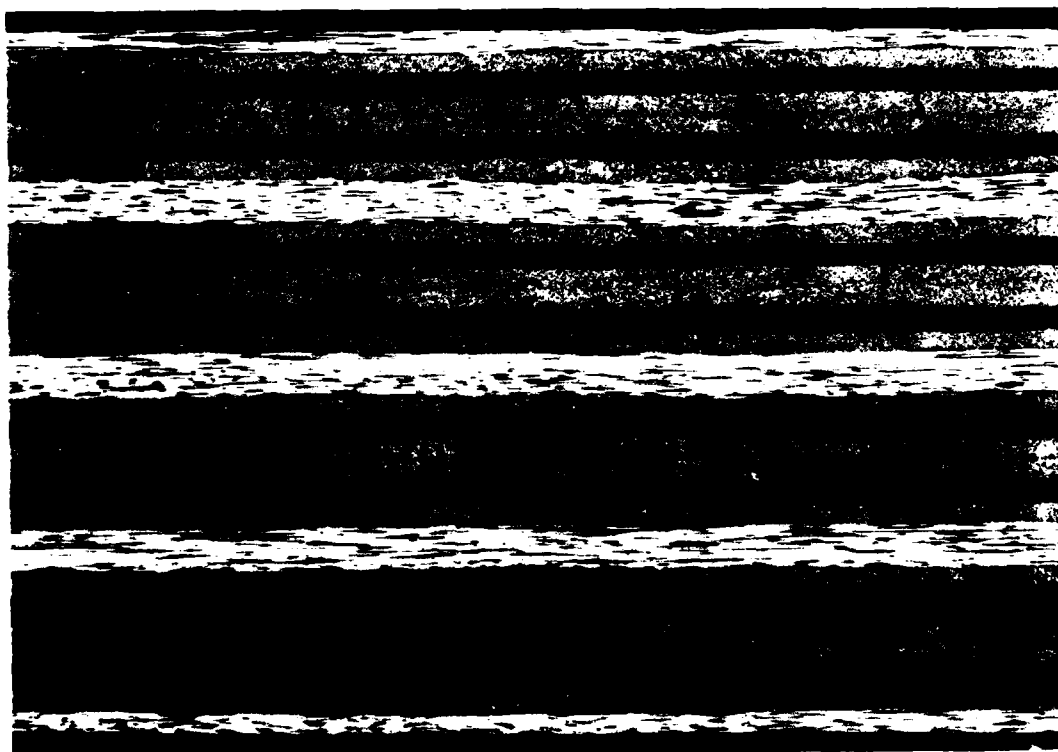
LOCATION: 1.74 IN. DAMAGE LENGTH: 0.781

G178



J30-11-1

10X



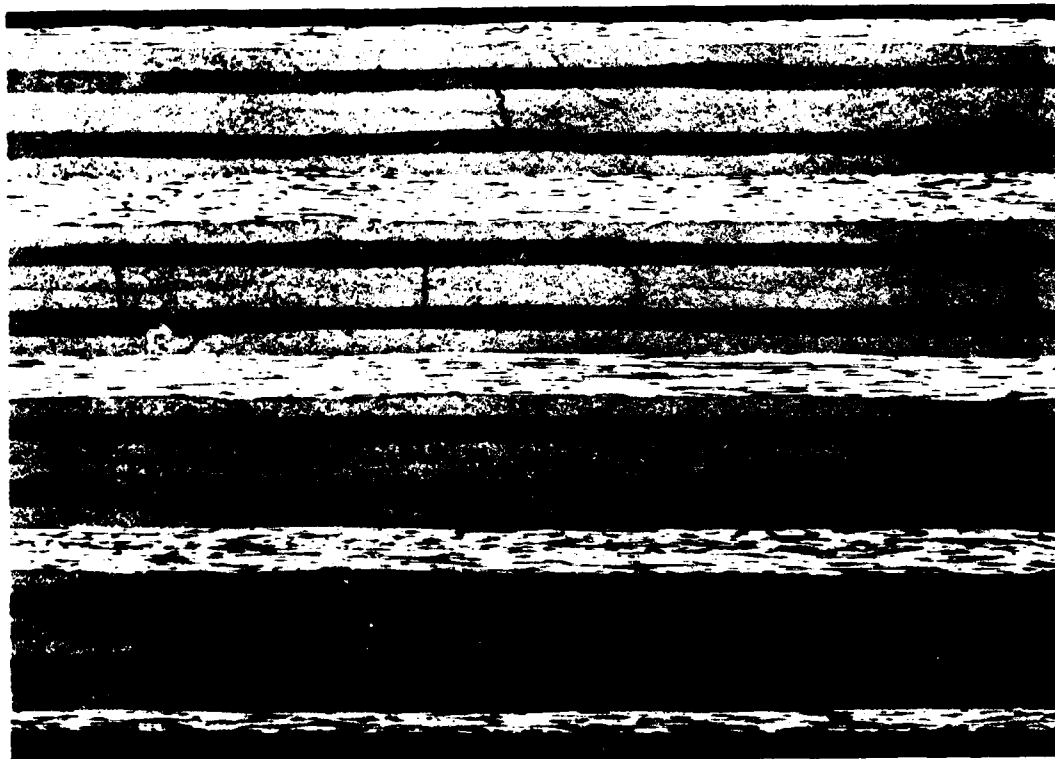
J30-11-2

25X

LOCATION: 1.84 IN. DAMAGE LENGTH: 0.762



J30-12-1



J30-12-2

25X

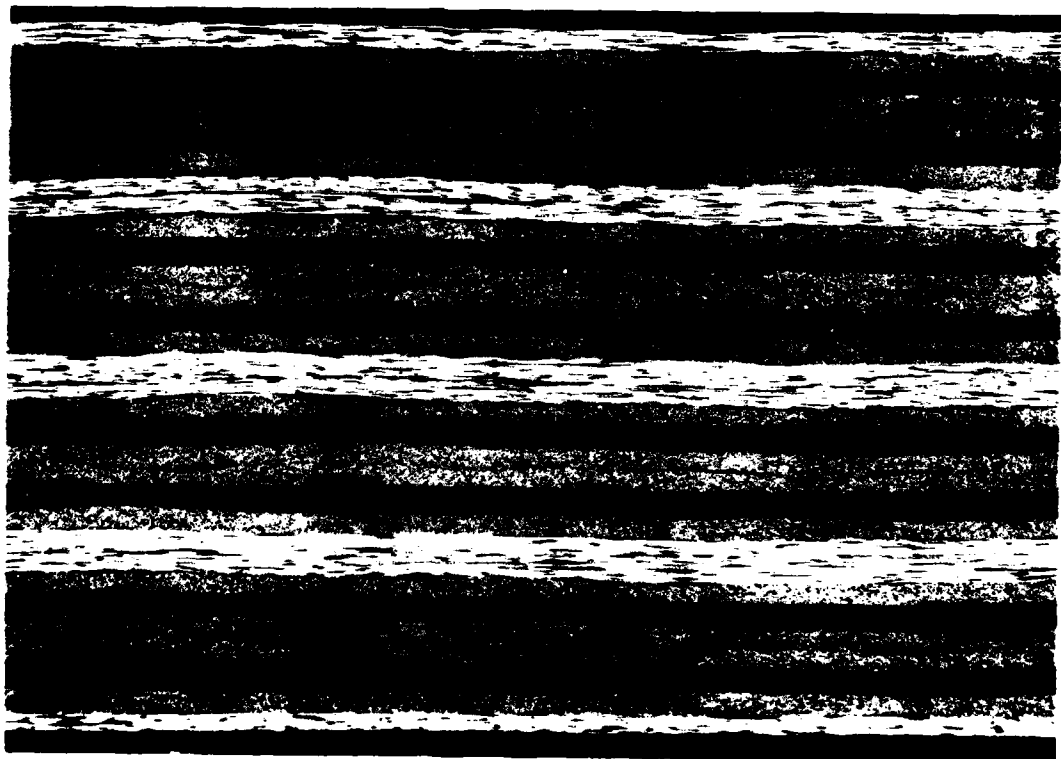
LOCATION: 1.94 IN. DAMAGE LENGTH: 0.743

G180



J30-13-1

10X

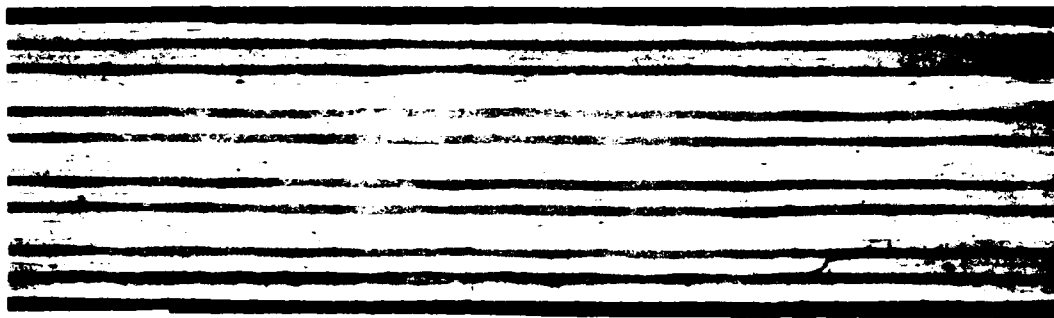


J30-13-2

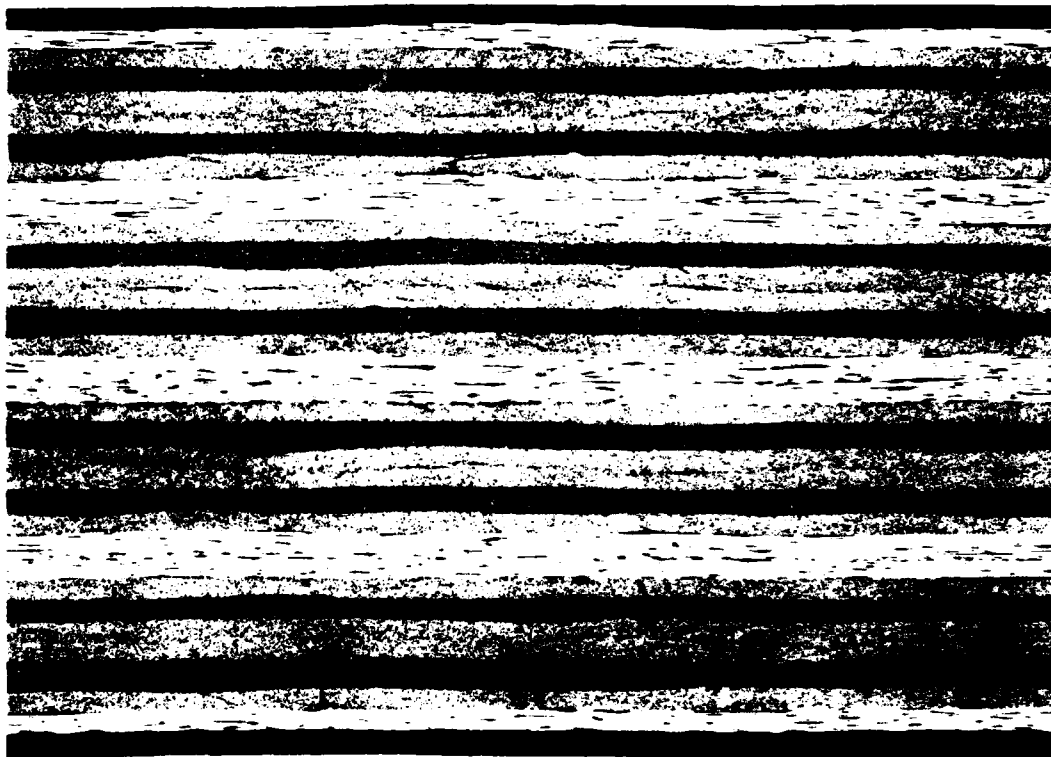
25X

LOCATION: 294 IN. DAMAGE LENGTH: 0.658

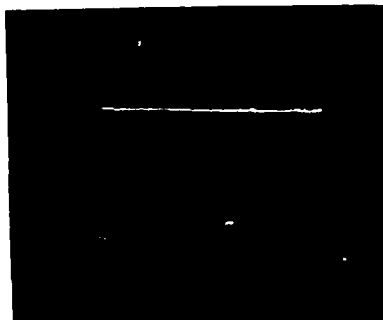
G181



J30-14-1



J30-14-2



B-SCAN AT 2.16 IN.

LOCATION: 2.14 IN. DAMAGE LENGTH: 0.577

G182



J30-15-1

10X

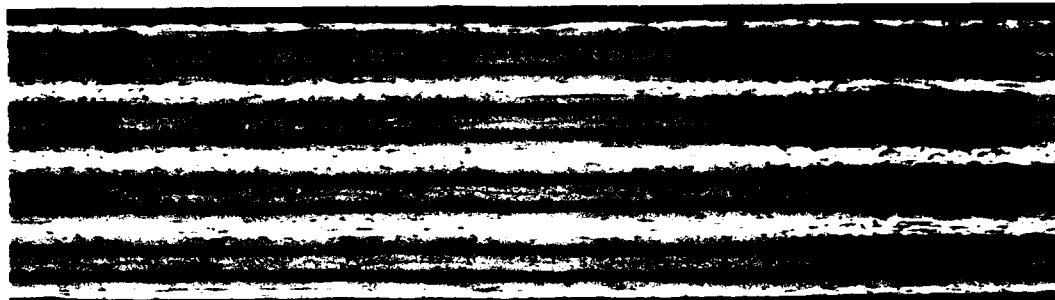


J30-15-2

25X

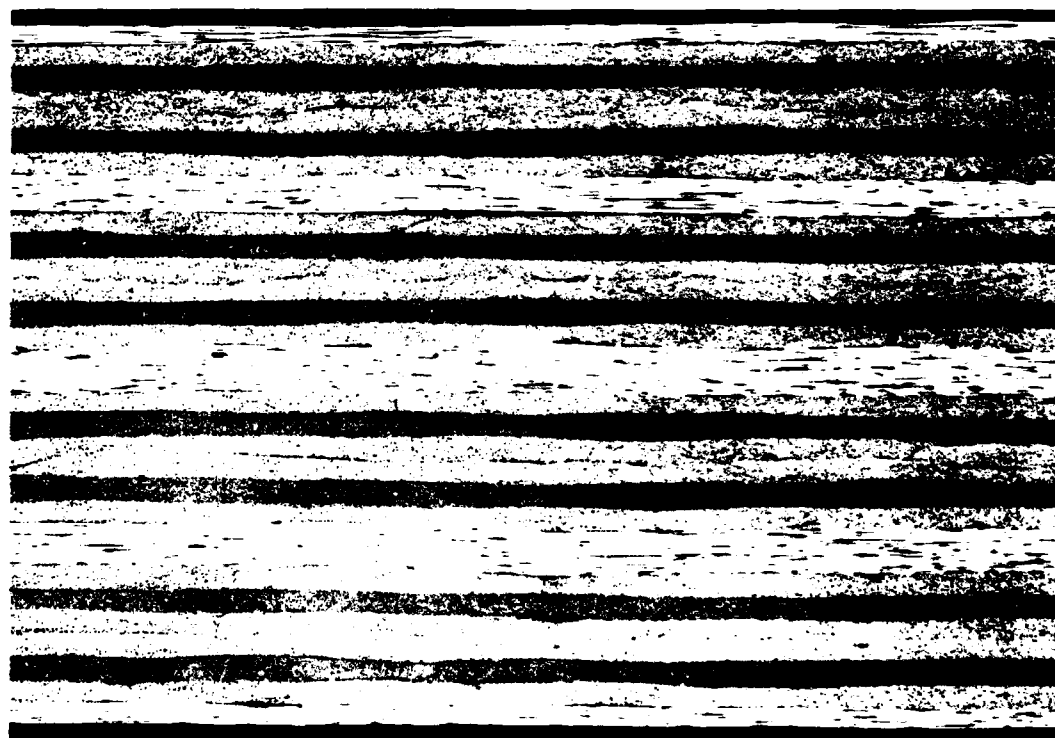
LOCATION: 2.24 IN. DAMAGE LENGTH: 0.280

G183



J30-16-1

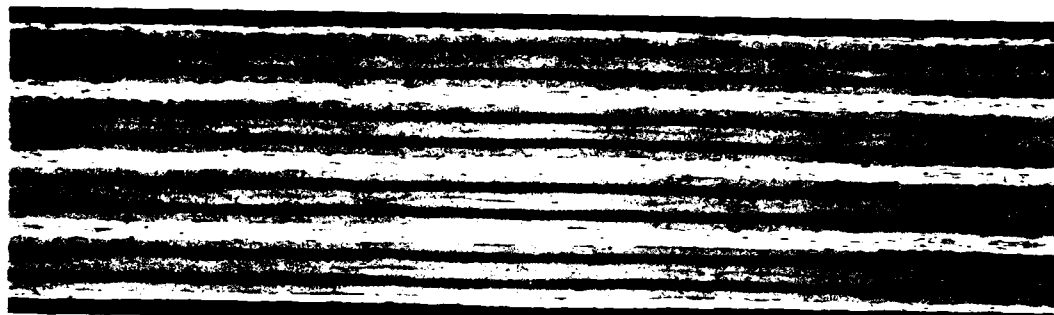
10X



J30-16-2

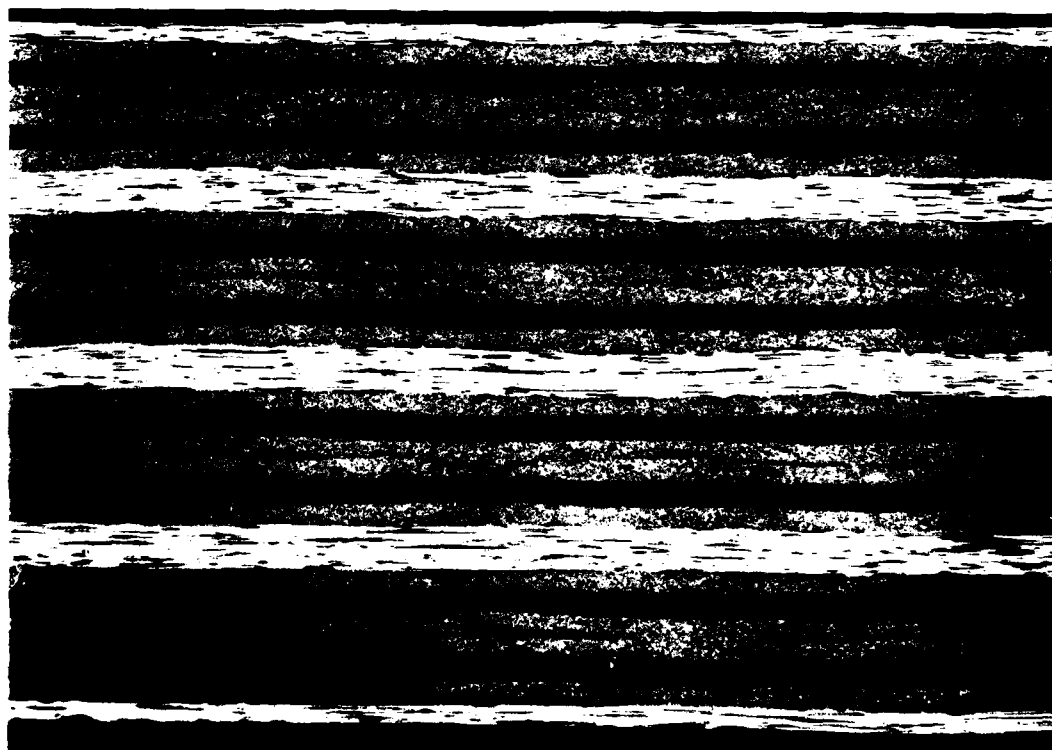
25X

LOCATION: 2.34 IN. DAMAGE LENGTH: ONE TRANS PLY CRACK



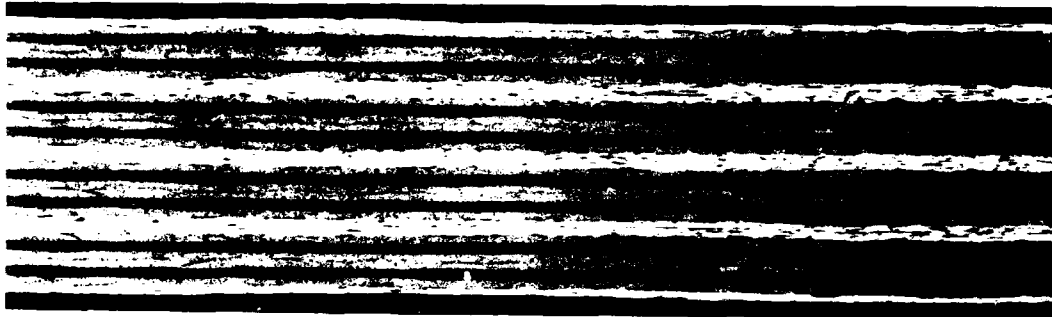
J30-17-1:

10X



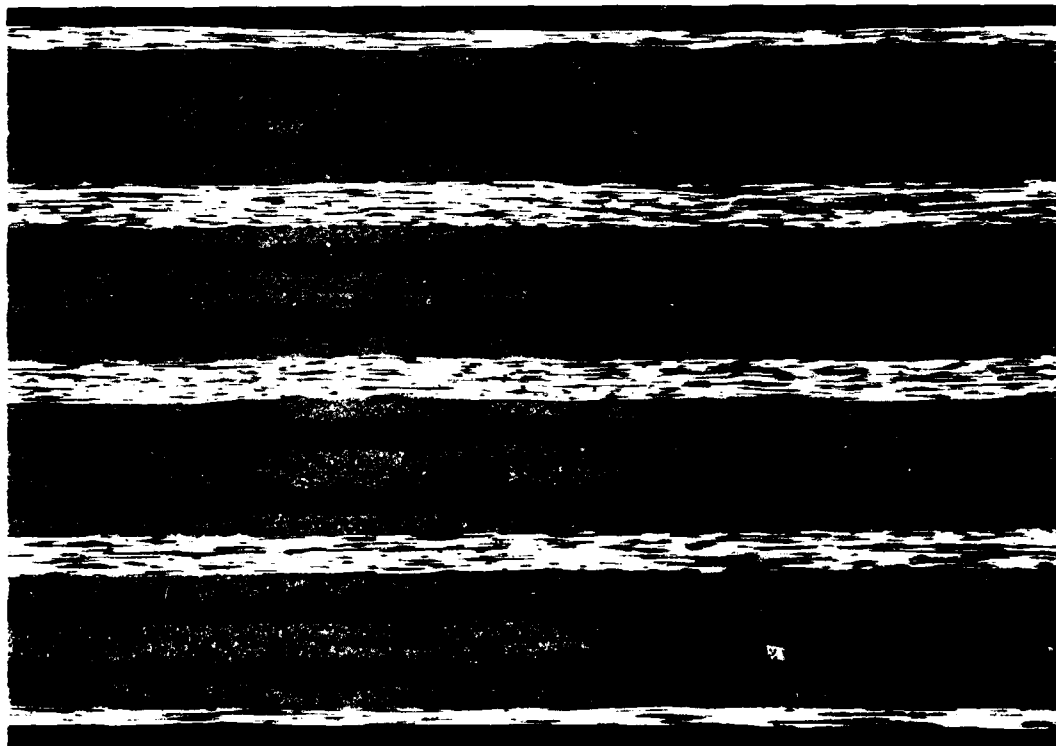
25X

MADE IN THE U.S. TRANS PLY CRACK



J30-18-1

10X



J30-18-2

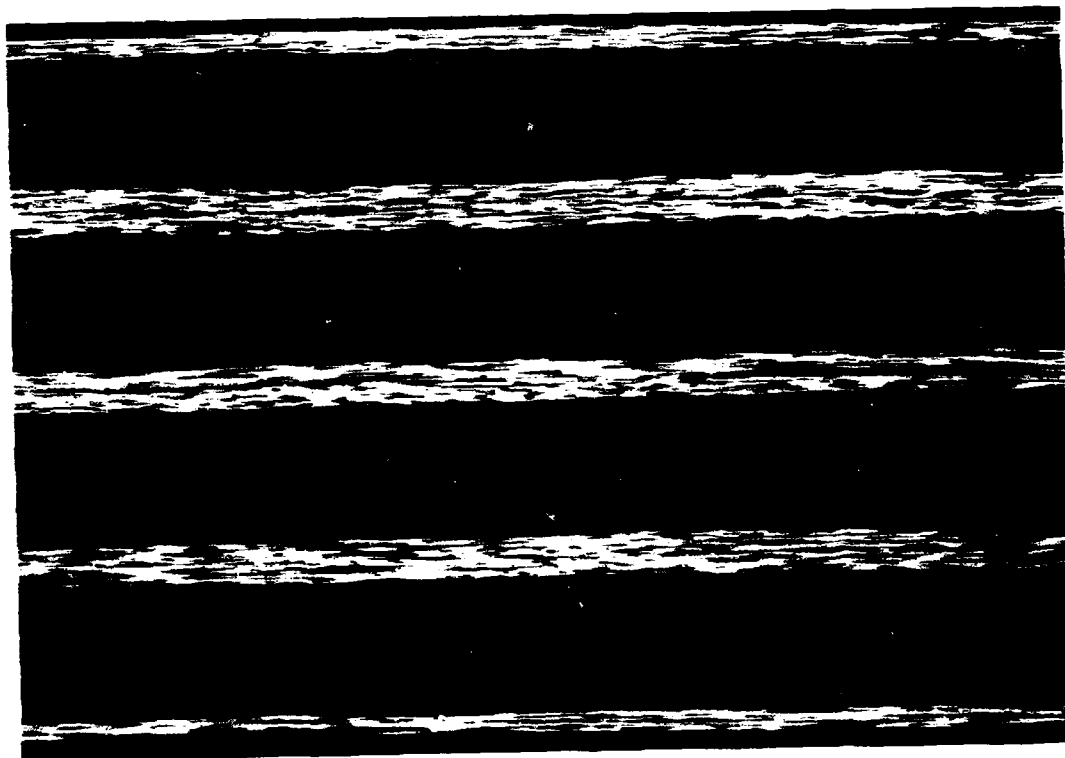
25X

LOCATION: 2.54 IN. DAMAGE LENGTH: ONE TRANS PLY CRACK



J30-19-1

10X



J30-19-2

25X

LOCATION: 2.64 IN. DAMAGE LENGTH: NO DAMAGE

G187

APPENDIX H

Comparison of Damage as Determined by
Holscan Ultrasonic C-Scan and DIB Enhanced X-ray



FIGURE H1: SPECIMEN NO. EB-i4 N = 4,000 CYCLES

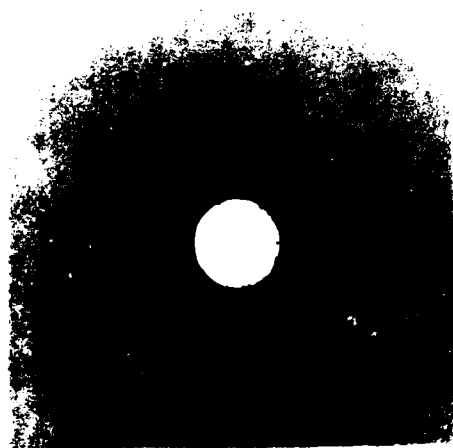


FIGURE H2: SPECIMEN NO. 1A-5 N = 4,000 CYCLES
24-PLY



FIGURE H3: SPECIMEN NO. FA-6 N = 8,000 CYCLES
24-PLY

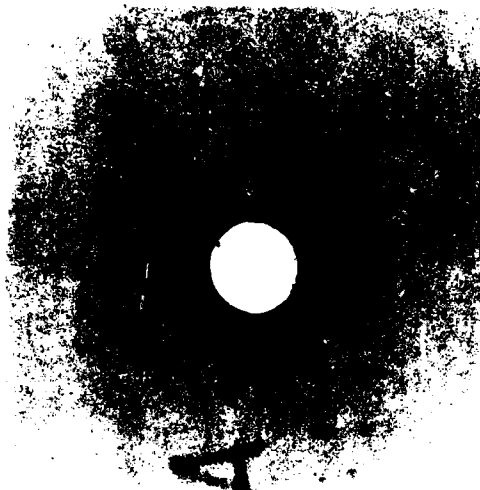
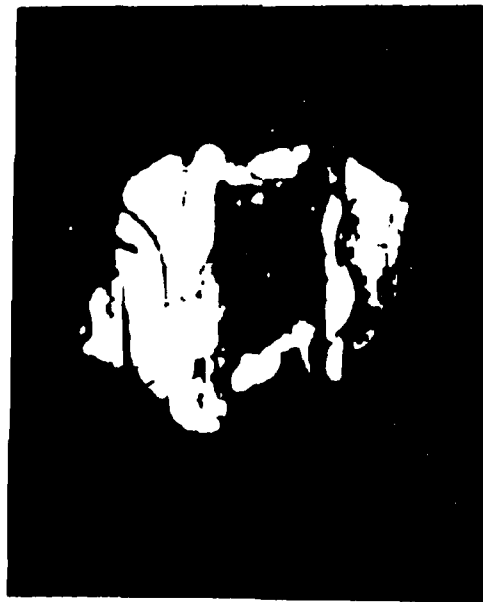


FIGURE H4: SPECIMEN NO. HA-8 N = 12,000 CYCLES
24-PLY



FIGURE H5: SPECIMEN NO. GC-23 N = 20,000 CYCLES

24-PLY

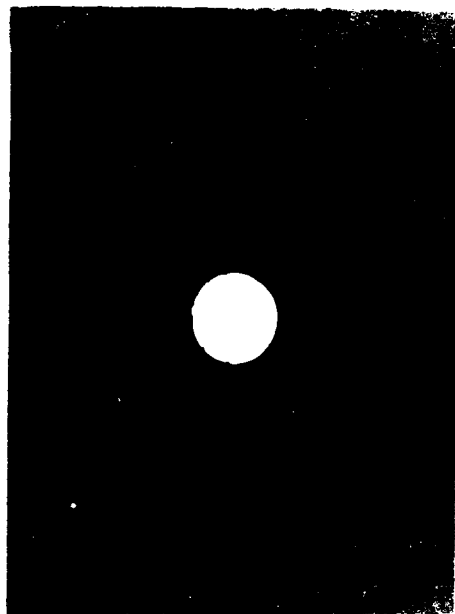


FIGURE H6: SPECIMEN NO. 0A-4 N = 1,000 CYCLES
32-PLY

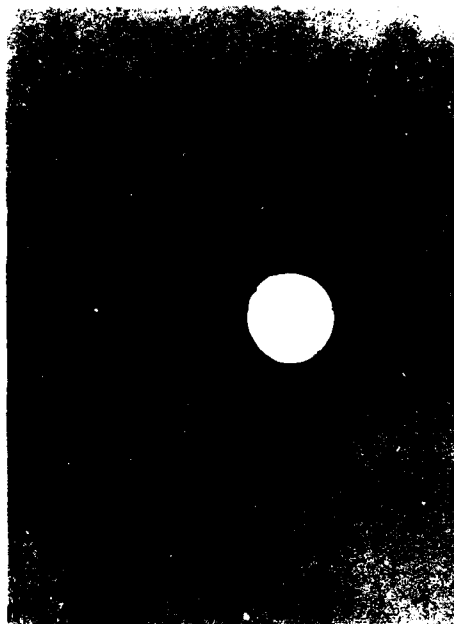


FIGURE H7: SPECIMEN NO. RC-29 N = 1,000 CYCLES
32-PLY

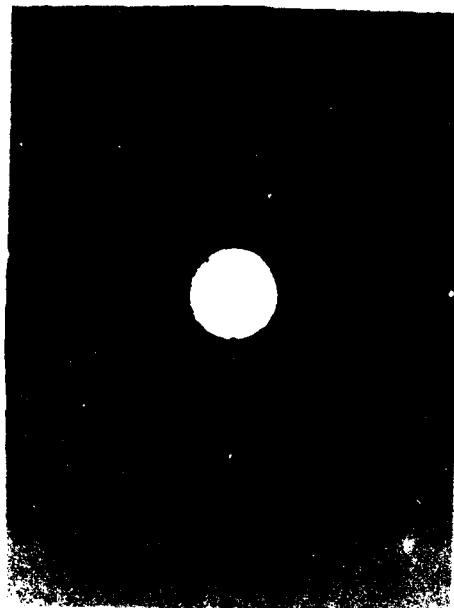
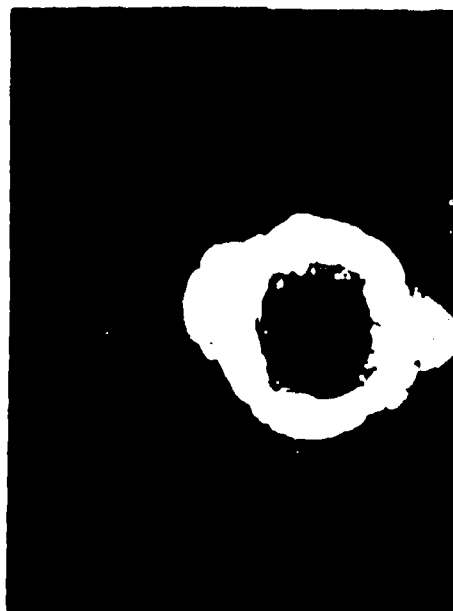


FIGURE H8: SPECIMEN NO. RB-19 N = 5,000 CYCLES
32-PLY

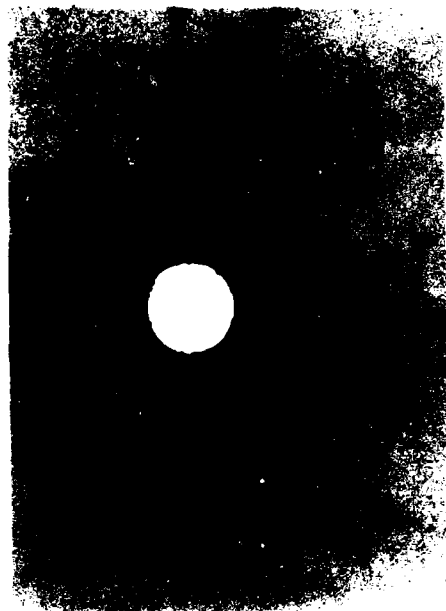


FIGURE H9: SPECIMEN NO. PC-21 N = 10,000 CYCLES

32-PLY

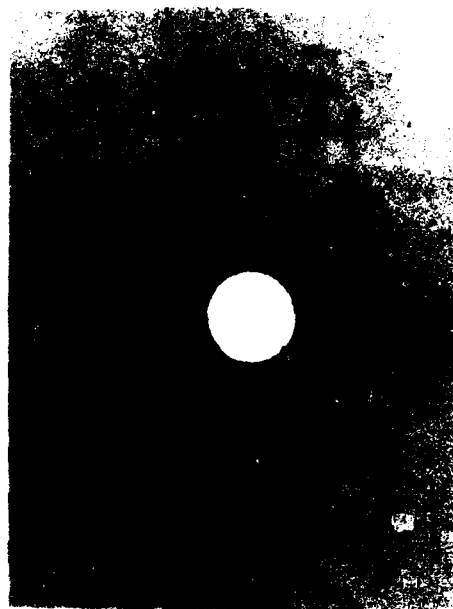


FIGURE H10: SPECIMEN NO. QC-24 N = 28,000 CYCLES
32-PLY

F/G 11/4

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5.

FND

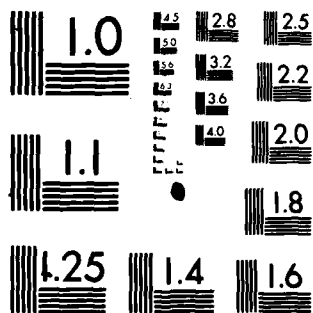
DATE _____

SUMMARY

7

DTIC

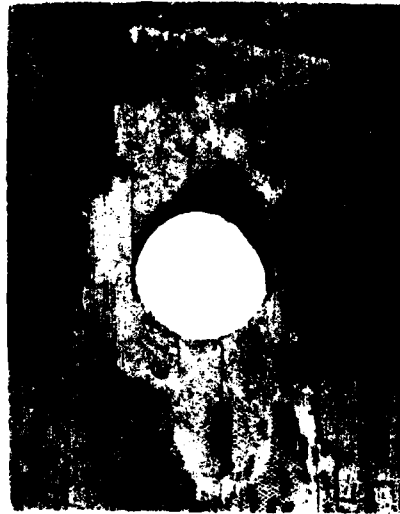
11518



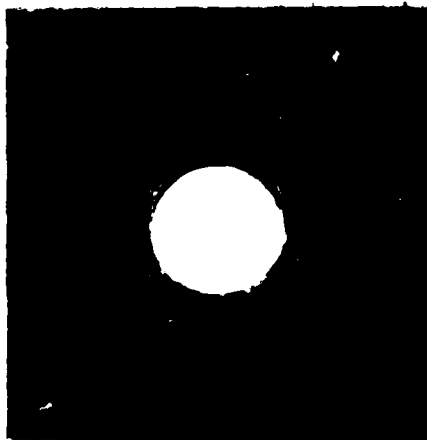
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX I

Damage on Individual Layers of
Specimens Deplied after Fatigue Cycling



I-5-1
PLY 1 0°



I-5-2
PLY 2 45°



I-5-3
PLIES 3 & 4, 0°

Figure 11a: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles
(Plies 1 - 3)

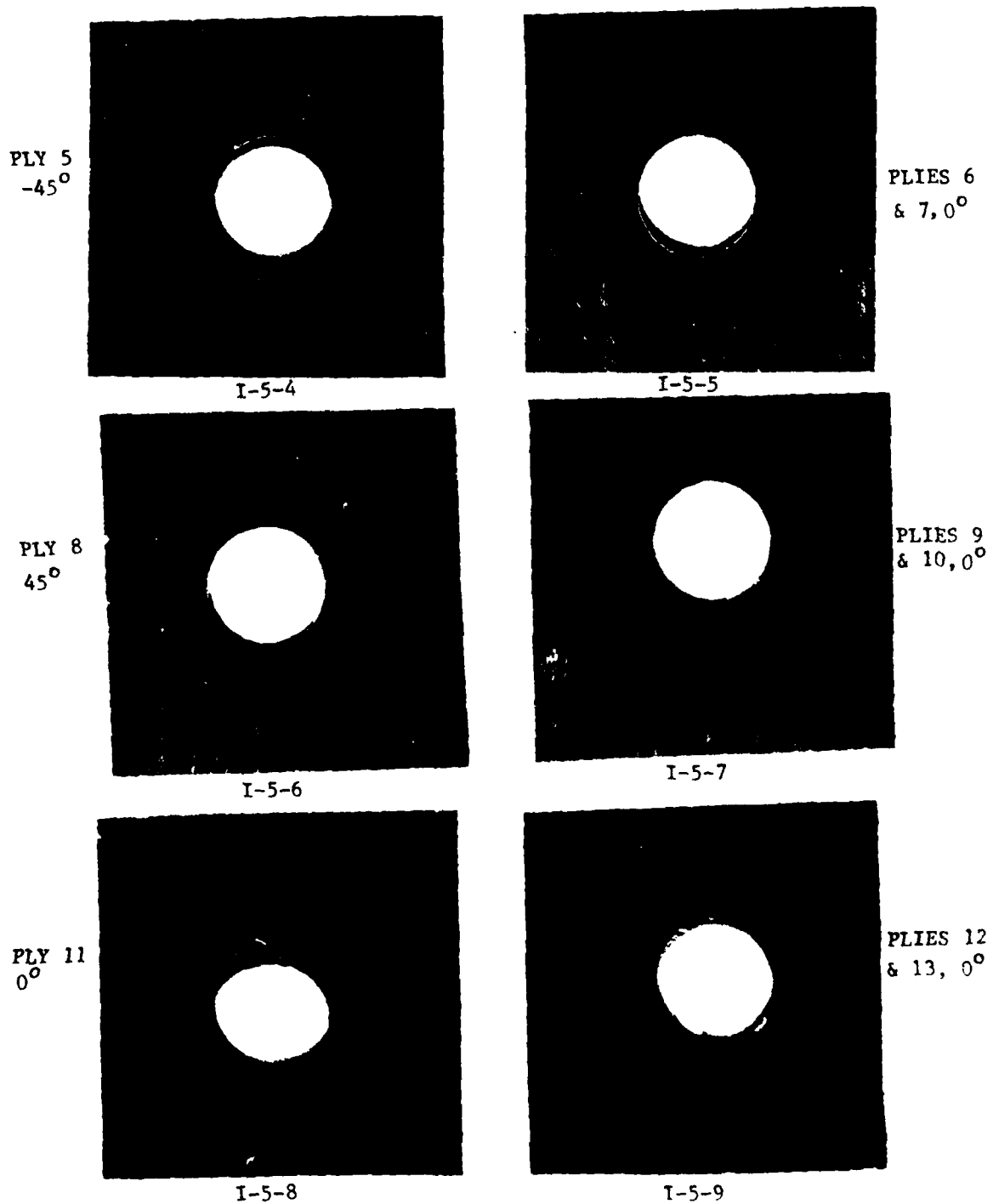


Figure 11b: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles
(Plies 4 - 9)

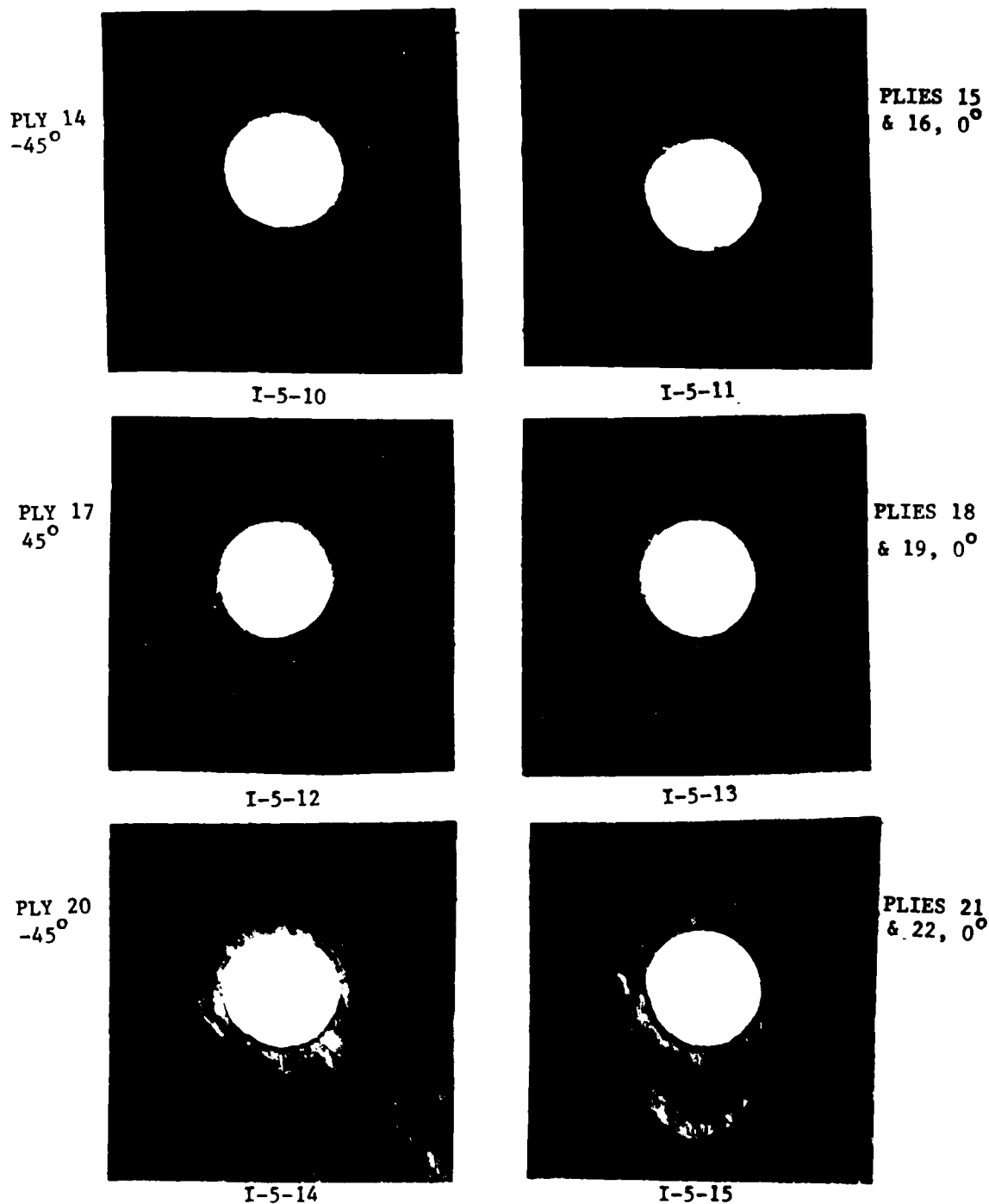
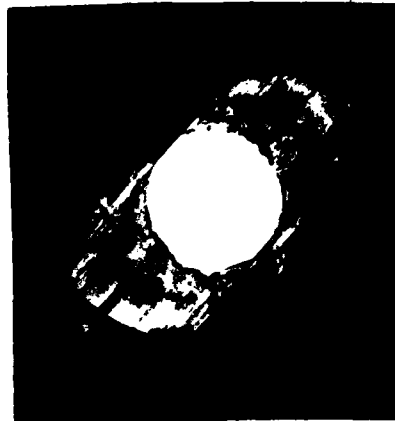


Figure 11c: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles
(Plies 10 - 15)



I-5-16
PLY 23, 45°

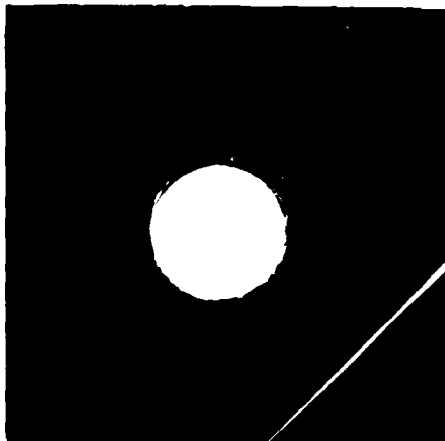


I-5-17
PLY 24, 0°

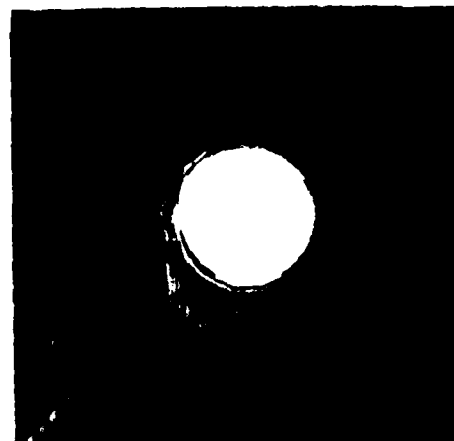
Figure IId: Deplied 24-Ply Specimen IA-5 After 4,000 Cycles
(Plies 15 - 17)



H-8-1
PLY 1, 0°

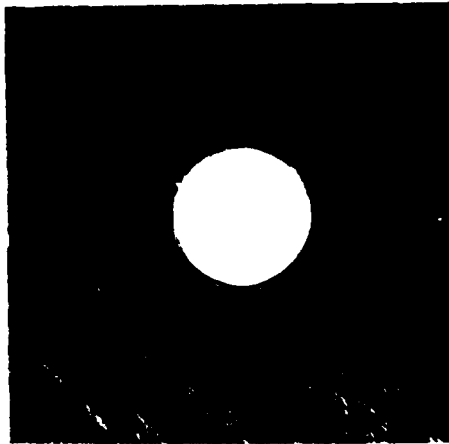


H-8-2
PLY 2, 45°

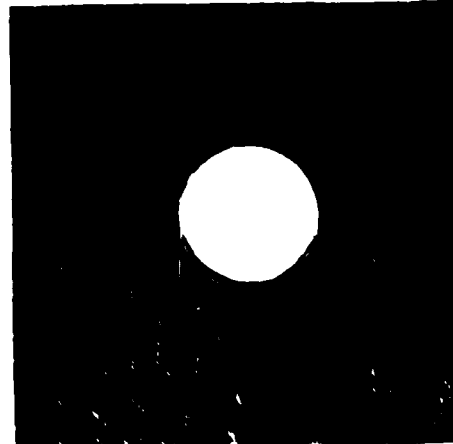


H-8-3
PLIES 3 & 4, 0°

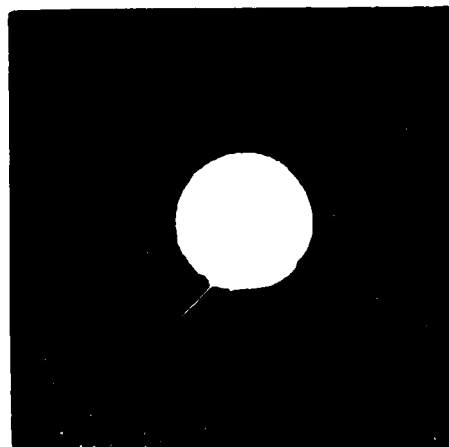
Figure I2a: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 1 - 3)



H-8-4
PLY 5, -45°



H-8-5
PLIES 6 & 7, 0°



H-8-6
PLY 8, 45°

Figure I2b: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 4 - 6)

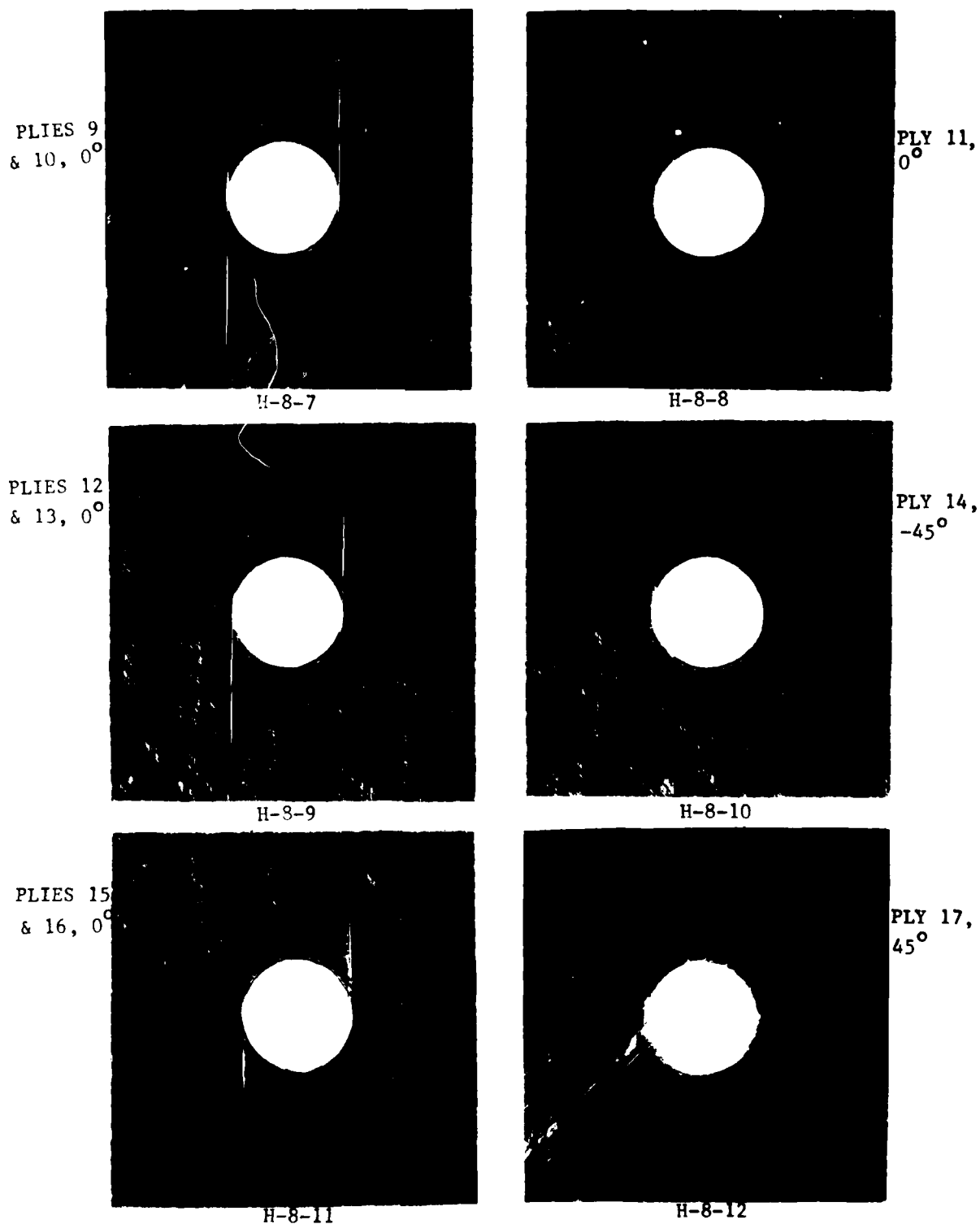
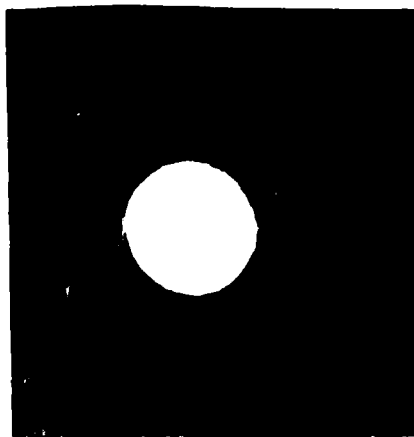


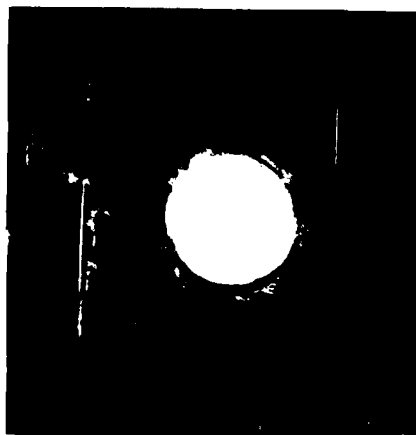
Figure I2c: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 7 - 12)



H-8-13
PLIES 18 & 19, 0°

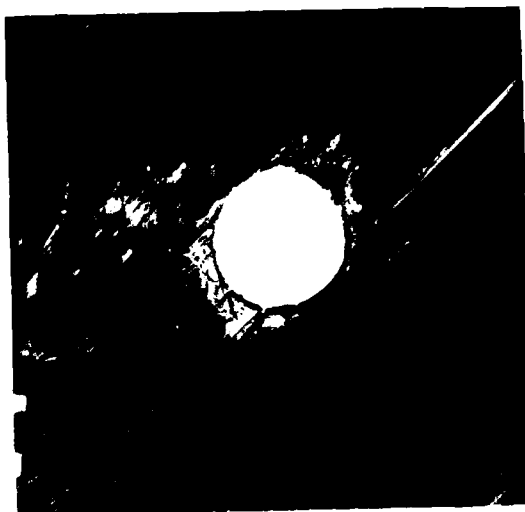


H -8-14
PLY 20, -45°



H-8-15
PLIES 21 & 22, 0°

Figure 12d: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 13 - 15)

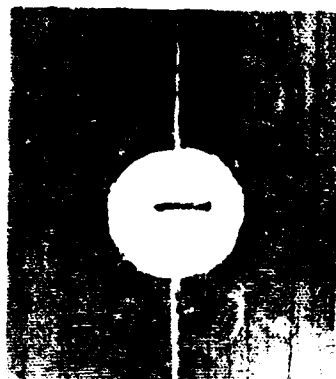


PLY 23, 45°

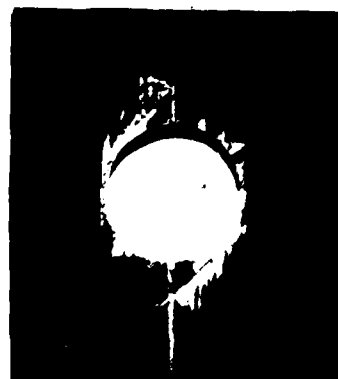


PLY 24, 0°

Figure I2e: Deplied 24-Ply Specimen HA-8 After 12,000 Cycles
(Plies 16 - 17)



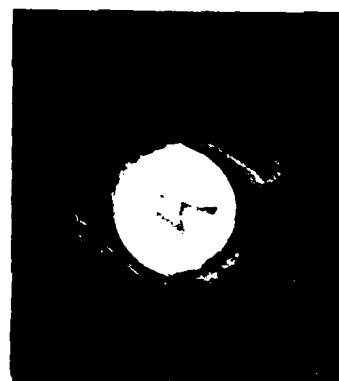
Q-4-1
PLY 1, 0°



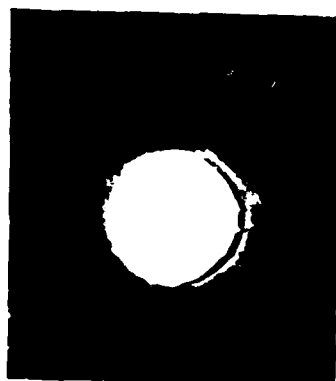
Q-4-2
PLY 2, 45°



Q-4-3
PLY 3, 90°



Q-4-4
PLIES 4 & 5, -45°

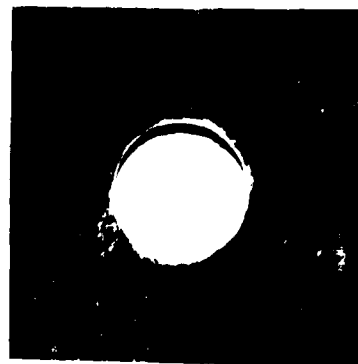


Q-4-5
PLY 6, 90°



Q-4-6
PLY 7, 45°

Figure I3a: Deplied 32-Ply Specimen OA-4 After 1,000 Cycles
(Plies 1 - 6)



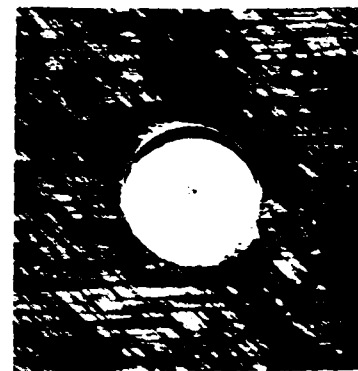
Q-4-7
PLIES 3 & 9, 0°



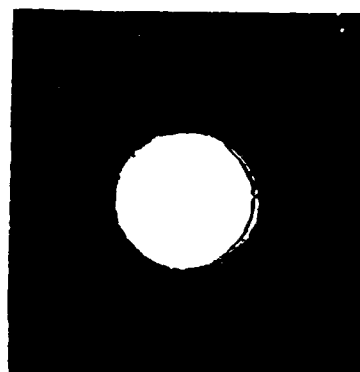
Q-4-8
PLY 10, 45°



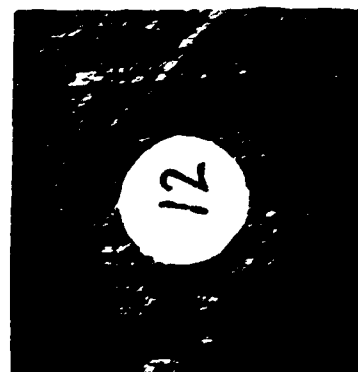
Q-4-9
PLY 11, 90°



Q-4-10
PLIES 12 & 13, -45°

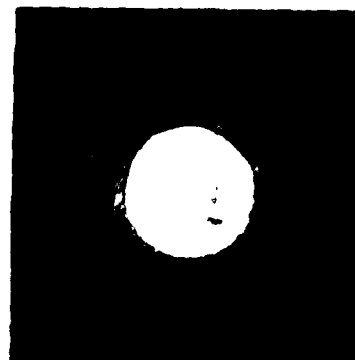


Q-4-11
PLY 14, 90°

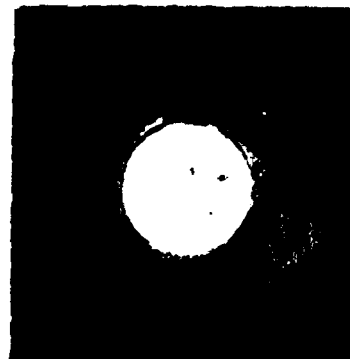


Q-4-12
PLY 15, 45°

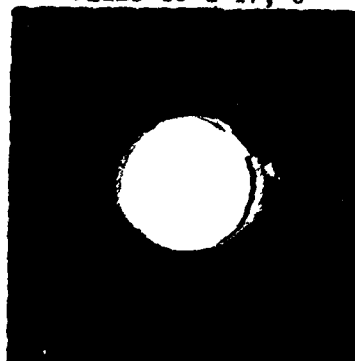
Figure I3b: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 7 - 12)



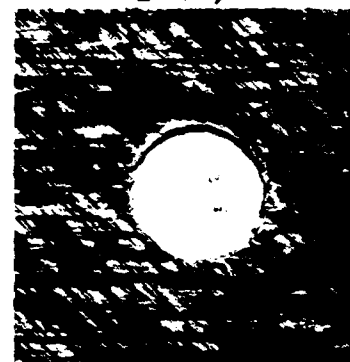
Q-4-13
PLIES 16 & 17, 0°



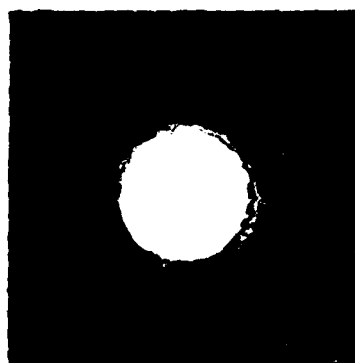
Q-4-14
PLY 18, 45°



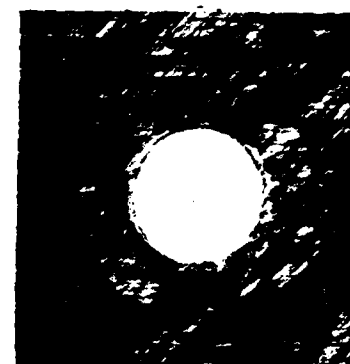
Q-4-15
PLY 19, 90°



Q-4-16
PLIES 20 & 21, -45°

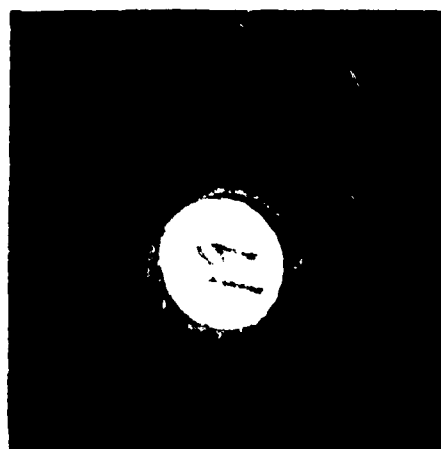


Q-4-17
PLY 22, 90°

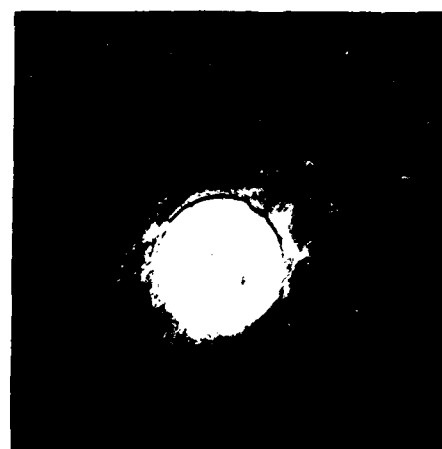


Q-4-18
PLY 23, 45°

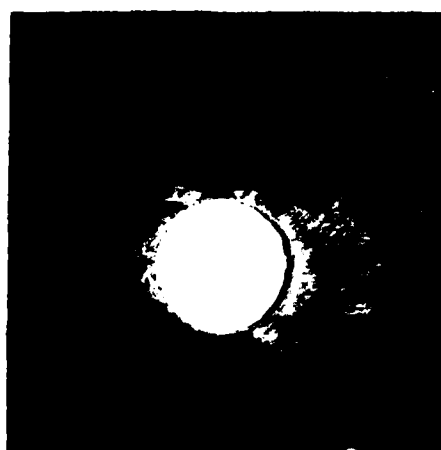
Figure 13c: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 13 - 18)



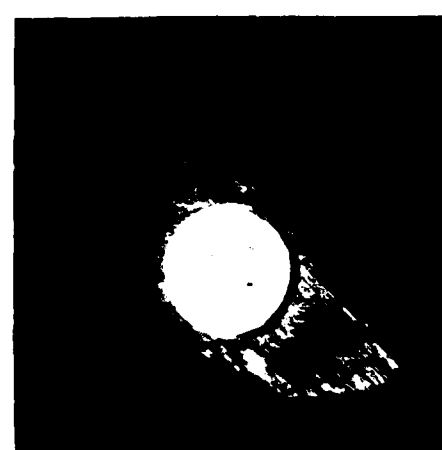
Q-4-19
PLIES 24 & 25, 0°



Q-4-20
PLY 26, 45°

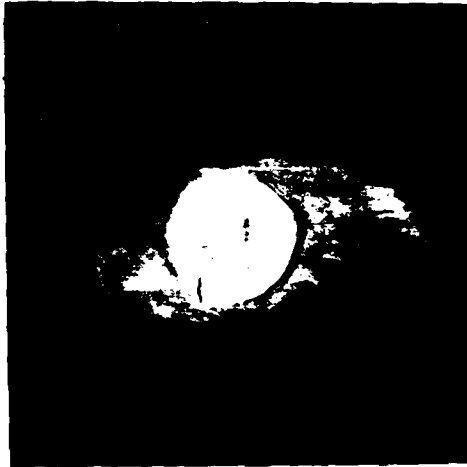


Q-4-21
PLY 27, 90°



Q-4-22
PLIES 28 & 29, -45°

Figure I3d: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 19 - 22)



Q-4-23
PLY 30, 90°



Q-4-24
PLY 31, 45°



Q-4-25
PLY 32, 0°

Figure 13e: Deplied 32-Ply Specimen QA-4 After 1,000 Cycles
(Plies 23 - 25)

APPENDIX J

Statistical Analysis of Panel Variability

APPENDIX J STATISTICAL ANALYSIS OF PANEL VARIABILITY

Due to the large number of specimens required for Task II, nine panels of each laminate type were fabricated. Considerable care was taken to produce panels under nearly identical conditions. All foreseeable variables were evaluated and specimens not meeting strict tolerance requirements were discarded as discussed in Volume I. The Task II static data were evaluated using several statistical procedures to determine whether the nine panel samples can be assumed to have come from the same population. Static data were normalized on the mean for each group of tests outlined in Test Plan Items 1-4, 6, 7 and 9 (See Table II of Vol. II). These results are presented in rank order by panel in Tables J1 and J2. The Wald-Wolfowitz^(J1) test which determines whether two samples come from populations having identical cumulative distribution functions was performed for the 24-ply and 32-ply panel data sets.

The two series of data points from 24-ply panels A and D, having the lowest and highest means, respectively were pooled in rank order. If the strength value was from panel A, a 0 was entered, if from panel D, a 1. This resulted in the following array for the combined 34 data points.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>
0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1
<u>29</u>	<u>30</u>	<u>31</u>	<u>32</u>	<u>33</u>	<u>34</u>																						
1	1	1	1	1	1																						

If $|u - \bar{u}| \geq \sigma_u t_{\alpha/2}$, the hypothesis that the two samples come from populations having identical cumulative distribution functions (c.d.f's) is rejected at the α level; where u is the number of runs and \bar{u} and σ_u^2 are the mean and variance of u respectively. For this case $|u - \bar{u}| = 5.76$ and $\sigma_u t_{\alpha/2} = 5.55$. Therefore, the hypothesis is rejected at the 5% risk of error.

Table J1 Normalized Static Data^a Rank Ordered By
Panel for the 24-Ply Laminate - Task II

PANEL IDENTIFICATIONS:

	A	B	C	D	E	F	G	H	I
1.	0.813	0.932	0.927	0.928	0.837	0.870	0.897	0.837	0.925
2.	0.871	0.974	0.967	0.931	0.890	0.893	0.939	0.901	0.953
3.	0.915	0.981	0.968	0.932	0.933	0.893	0.947	0.910	0.955
4.	0.923	0.986	0.971	0.955	0.960	0.919	0.960	0.911	0.957
5.	0.962	0.987	0.975	0.991	0.964	0.943	0.984	0.947	0.975
6.	0.968	0.996	0.978	1.000	0.976	0.977	0.986	0.955	0.989
7.	0.968	1.011	0.986	1.009	0.983	0.980	0.986	0.964	0.993
8.	0.973	1.014	0.989	1.021	0.995	0.990	0.992	0.965	0.994
9.	0.975	1.016	0.992	1.070	0.999	0.995	0.994	1.018	1.008
10.	0.980	1.018	0.994	1.071	1.010	0.997	0.997	1.019	1.011
11.	0.990	1.022	1.009	1.073	1.011	1.014	1.000	1.034	1.014
12.	0.993	1.025	1.012	1.075	1.020	1.016	1.007	1.077	1.017
13.	0.999	1.033	1.019	1.087	1.033	1.024	1.018	1.174	1.018
14.	1.002	1.044	1.057	1.100	1.039	1.030	1.040		1.019
15.	1.013	1.065	1.067	1.144	1.071	1.035	1.048		1.038
16.	1.014	1.083	1.104		1.094	1.046	1.050		1.091
17.	1.020		1.140		1.126	1.062	1.052		
18.	1.034					1.062	1.065		
19.	1.035					1.110	1.076		
20.						1.132	1.114		
\bar{X}	0.971	1.012	1.009	1.026	0.997	0.999	1.008	0.978	0.997
SD	0.056	0.037	0.054	0.069	0.071	0.070	0.052	0.087	0.040
CV%	5.81	3.61	5.38	6.71	7.08	7.01	5.13	8.92	3.97

a = Includes all test data from Task II Test Plan Items 1-4, 6, 7 and 9
(See Table II of Vol. II)

NOTE: \bar{X} = Mean, SD = Standard Deviation, CV% = Coef. of Var. %

Table J2 Normalized Static Data^a Rank Ordered By
Panel for the 32-Ply Laminate - Task II

PANEL IDENTIFICATIONS:

	J	K	L	M	N	P	Q	R	S
1.	0.883	0.947	0.882	0.878	0.782	0.927	0.913	0.904	0.857
2.	0.897	0.953	0.937	0.898	0.918	0.967	0.927	0.919	0.920
3.	0.919	0.960	0.956	0.938	0.934	0.972	0.942	0.923	0.924
4.	0.928	0.962	0.969	0.953	0.939	0.976	0.945	0.929	0.939
5.	0.939	0.965	0.972	0.954	0.949	0.983	0.947	0.933	0.954
6.	0.953	0.976	0.977	0.961	0.958	0.985	0.963	0.943	0.954
7.	0.965	0.977	0.978	0.971	0.960	0.995	0.964	0.948	0.956
8.	0.988	0.980	0.979	0.987	0.965	0.995	0.965	0.964	0.986
9.	0.993	0.989	1.006	0.987	0.979	1.006	0.968	0.964	0.989
10.	0.998	0.990	1.008	0.997	0.981	1.007	0.968	0.983	0.990
11.	0.999	0.991	1.009	1.008	0.984	1.019	0.995	0.987	0.991
12.	1.003	0.997	1.026	1.028	0.985	1.031	0.999	1.006	0.992
13.	1.009	1.004	1.030	1.059	1.001	1.039	1.007	1.007	1.000
14.	1.015	1.008	1.030	1.065	1.002	1.044	1.018	1.019	1.006
15.	1.019	1.009	1.035	1.068	1.004	1.050	1.059	1.031	1.009
16.	1.050	1.012	1.055	1.085	1.008	1.051	1.063	1.035	1.012
17.	1.053	1.018	1.061	1.102	1.014	1.087	1.064	1.049	1.038
18.	1.073	1.025	1.062	1.157	1.016	1.091	1.079	1.085	1.053
19.	1.076	1.043	1.080	1.176	1.045	1.120	1.082	1.117	
20.		1.049			1.062	1.156	1.168	1.154	
21.		1.144			1.072				
22.		1.192			1.140				
\bar{X}	0.987	1.009	1.003	1.014	0.986	1.025	1.002	0.995	0.976
SD	0.056	0.059	0.049	0.081	0.068	0.056	0.065	0.069	0.047
CV%	5.72	5.83	4.92	8.01	6.92	5.50	6.52	6.89	4.80

^a = Includes all test data from Task II Test Plan Items 1-4, 6, 7 and 9
(See Table II of Vol. II)

NOTE: \bar{X} = Mean, SD = Standard Deviation, CV% = Coef. of Var. %

However, the hypothesis cannot be rejected at the same level when the test is performed on the second highest (B) and second lowest (H) panels.

Performance of the Wald-Wolfowitz test on the 32-ply panels having the lowest (S) and highest (P) means yields the following array for the combined 38 data points:

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>	<u>25</u>	<u>26</u>	<u>27</u>	<u>28</u>
0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	0	1	0	1	0	0	1	1
<u>29</u>	<u>30</u>	<u>31</u>	<u>32</u>	<u>33</u>	<u>34</u>	<u>35</u>	<u>36</u>	<u>37</u>	<u>38</u>																		
0	1	1	1	1	0	1	1	1	1																		

where a 0 was entered if the value came from panel S and 1 if from D. Here $|u - \bar{u}| = 3.95$ and $\sigma_u t_{\alpha/2} = 5.94$. Hence, the hypothesis that the samples have identical c.d.f.s cannot be rejected for a risk of error of 5%. For the 32-ply panels, then, it appears likely that the strength data for all of the panels belong to the same population.

Since 24-ply panels A and D appeared to have different c.d.f.'s several additional tests were performed.

Applying the Chi-squared test to samples A and D indicates that there is a high probability (at $\alpha = 0.05$) the distributions are normal. Thus the F-test and T-test were then applied.

The quantity F is the ratio of the two sample variances,

$$F = S_A^2 / S_D^2$$

If the variances of samples A and D are identical at a significance level of $\alpha = 0.05$, F should be between the boundaries defined by $F_{0.975}$ and $1/F_{0.975}$, for $N_A - 1$ and $N_D - 1$ degrees of freedom. F does lie in this interval since $F = 0.670$, $1/F_{0.975} = 0.37$ and $F_{0.975} = 2.88$. Thus the variances can be assumed to be the same within 0.05 risk of error. This indicates

the two samples may belong to the same population, i.e. have the same scatter or dispersion.

The T-test was used to determine whether the means differ significantly. The absolute differences between the means is calculated by:

$$D_{\bar{x}} = |\bar{x}_A - \bar{x}_D|$$

If the means do not differ, $D_{\bar{x}}$ should not exceed u where

$$u = t_{0.975} S_p \sqrt{\frac{n_A + n_D}{n_A n_D}}$$

for $\alpha = 0.05$. For this case $D_{\bar{x}} = 0.055$ and $u = 0.0438$. Since $D_{\bar{x}} > u$ there is reason to believe samples might not be from the same population.

Based on these three tests, Wald-Wolfowitz, F-test and T-test the statement cannot be made that panel A and D data have the same cumulative distribution functions within a 0.05 risk of error.

This does not necessarily mean that the samples are from different populations although that possibility is definitely suggested. The many assumptions implicit in this type of statistical evaluation must be considered. No attempt was made to include fatigue data because the failure modes differ. However, all static data including tension, compression at high and low strain rates and residual strength data were normalized and combined. This in itself is a questionable procedure. Variables affecting stability under compression loading will not necessarily influence tension strength similarly especially for different strain rates and damage sizes. Data were pooled in order to obtain an adequate sample size to perform some evaluation of panel variability. If the data pooling were acceptable, it appears that except for the 24-ply panels A & D, all other panels are statistically identical. In fact, if the 24-ply panels were ranked by mean strength from low to high (A, H, E,

I, F, G, C, B, D) all adjacent panels would be identical. The panels form a smooth distribution with A and D at the tails. Thus a single "bad" panel cannot be identified.

APPENDIX K
DISCUSSION OF WEIBULL FUNCTION
AND PARAMETER ESTIMATION PROCEDURES

APPENDIX K

K.1 GENERAL DISCUSSION OF WEIBULL FUNCTION

In Weibull's representation of the statistics of fatigue, there are two random variates at each stress test condition. The first of these variates is the ordered sequence of the numbers of cycles to failure for each test result, n_i :

$$n_i: (n_1, n_2, n_3 \dots n_N)$$

The second random variate, x , is continuous and is the argument of the Weibull survivorship function, or probability of survival, expressed as

$$P(x) = \exp [-((x-e)/(v-e))^k], \quad (K1)$$

where

$$x \geq e, v \geq e, k > 0, P(e) = 1, P(v) = 1/\exp(1)$$

The connection between the random variates, n_i and x , is entirely empirical. In practice, numerical procedures are used to derive the three Weibull parameters k , e , and v by means of the approximation:

$$P(x) = 1 - i/N \text{ when } x = n_i, \quad (K2)$$

or

$$P(x) = 1 - 1/(N + 1).$$

For Equation K1, the mean of the sample set is given by ^{K1}:

$$\bar{x} = e + (v-e) \Gamma(1 + 1/k) \quad (K3)$$

the median by:

$$\frac{U}{x} = e + (v-e)(\log_e 2)^{1/k} \quad (K4)$$

and the mode by:

$$\tilde{x} = e + (v-e)(1-1/k)^{1/k} \quad (K5)$$

where $\Gamma(\)$ indicates the Gamma function.

During the past twenty-five years, a number of names have been applied to the parameters. In general, parameters e and v are considered as scale parameters or factors and the exponent k as a shape parameter. The term threshold parameter is usually applied to parameter e and the term characteristic value to v . In analysis of composite data, k is frequently denoted by α and v by \hat{F} . The scale parameter, e , is often referred to as the minimum life estimate. With this choice of words, e is suggested on physical grounds to be $e \geq 0$. Many authors have reasoned further that since $e \ll n_i$, $i = 1, 2, 3, \dots, N$, the Weibull survivorship function can be appropriately reduced to dependence on two parameters, k and v , with $e = 0$ arbitrarily. An argument against this practice will be described in this section.

The influence of the shape parameter k can be explained as follows. Define a reduced variate Z as:

$$Z = (x-e)/(v-e), \quad Z \geq 0, \text{ dimensionless,} \quad (K6)$$

and express the probability of survival function as:

$$P(x) = \exp \left[-Z^k \right], \quad k > 0, \quad (K7)$$

where

$$P(Z) = 1/\exp(1) \text{ when } Z=1$$

and

$$P(Z) = 1 \text{ when } Z = 0, \text{ for all } k,$$

If $k < 1$, this is sometimes interpreted as implying that the material develops resistance to fatigue as the number of load cycles is increased. If $k = 1$, the Weibull survivorship function reduces to the constant failure rate relation commonly used in reliability studies. If $k > 1$, one can inquire whether the test material experiences progressive damage as numbers of load cycles are increased.

Figure K1 illustrates the manner in which $P(Z)$ is dependent on the shape parameter k for the range of the reduced variate Z from zero to two. Empirical evidence does not support the interpretation that k might be a smoothly increasing function of stress amplitude. For practical purposes, in the case of structural fatigue, the region of Figure K1 of most interest to designers is bounded as follows:

- (a) Above by the limit $P(Z) = 1.0$
- (b) Below by the median $P(Z) = 0.5$
- (c) On the left by the curve $P(Z) = \exp [-Z]$
- (d) On the right by the curve $P(Z) = \exp [-Z^{10}]$.

K.2 WEIBULL ANALYSIS PROCEDURES

There are three principal procedures which have been used to determine the Weibull parameters (k , e , and v) for a given data set. These are: the moment estimation (ME) method; the maximum likelihood estimation (MLE) procedure; and some form of the linear regression (LR) procedure. All three methods are also used to determine the unknown parameters of other types of fitting functions. The ME method principally consists of equating several population moments (equal to the number of unknown parameters) to the sample

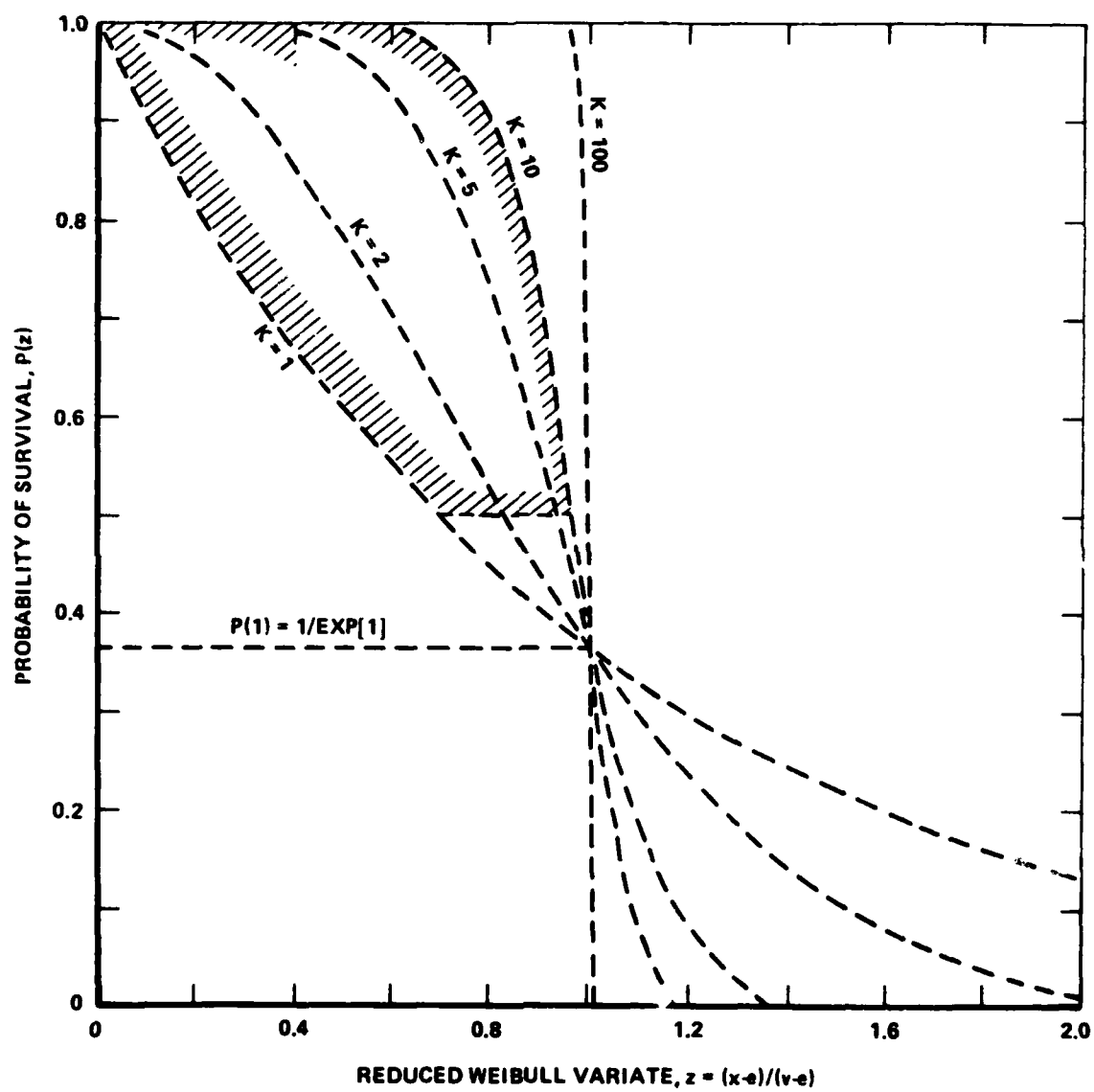


Figure K1 - Influence of shape parameter k on probability of survival

moments. The MLE method consists of setting the partial derivatives of the logarithm of $P(X)$, with respect to the parameters sought, equal to zero. In the LR procedure, the Weibull survivorship function is reduced to a linear equation. For the LR method, the solution for a two-parameter Weibull function is straightforward, but in the three-parameter case the solution is found by optimization of the correlation coefficient or by matching the sample skewness coefficient.

When one of the above described procedures was originally selected^{K2} for analyzing graphite/epoxy composite strength and fatigue data, consideration was given to two thoughts. First, how well does the resultant Weibull survivorship function represent the original data set? Second, what, if any, extrapolative potential exists for the resultant function? Consideration of these two questions led to the selection of the LR procedure. The reasons for this selection will be described in detail along with references to recent work which supports the original choice.

Both the ME and MLE methods require homogeneous samples. The reason for this requirement is that in the ME procedure the Weibull density function is integrated while in the MLE procedure, partial derivatives of the function are obtained. In this program, requirement of homogeneity was not assumed, a priori, to be necessarily met by sample information obtained from fracture data of composites. A procedure was desired which would be sensitive to the possible existence of multicomponent strength and fatigue life data. Such a requirement appears to be met by a LR procedure^{K3}. The ME method can result in significant errors in estimation of k , e , and v ^{K3} and such errors increase as k increases. In the case of two-parameters, errors in estimation of k and v increase linearly with the true value of e (assumed to be zero) and can be greater than 100% when $e \geq v$ ^{K3}. For the MLE procedure, three difficulties are encountered. First, the MLE solution of a data set is often a local maximum, but is not necessarily the maximum likelihood estimate^{K1-K7}. Weibull and Weibull^{K3} found in a study of 300 random samples

of 10 and 20 points each that approximately half of the estimates were not the maximum likelihood estimate, but were local maximums. Second, valid data sets can occur for which convergent solutions are not forthcoming, particularly for three parameter solutions^{K7}. Third, if a given data set which actually belongs to a three-parameter Weibull population is assumed to be a two-parameter population ($e = 0$), the estimates of k and v can be significantly higher than their true values^{K3}.

As previously alluded to in the analysis of graphite/epoxy composite data, the parameter e is often set equal to zero. This practice greatly simplifies the mathematics especially for MLE procedures; however, there are strong objections against such a practice^{K1,K3,K7}. These have already been discussed with reference to the ME and MLE procedures and are based upon the statistical error induced by the practice of setting $e = 0$. In summary, the three-parameter Weibull fit can be shown to fit the actual data set better than the two-parameter^{K2,K3,K7}. However, objections against the three-parameter Weibull fitting procedure are often raised upon the grounds that the parameter e may be found to have a negative value, particularly for a fatigue data set. The objection is thus raised that actual coupons can not have a finite probability of failure when the applied load is zero. Setting e equal to zero solves this problem. Setting e equal to zero is principally related to the question of the extrapolative capability of the Weibull function for graphite/epoxy composite fracture data.

Setting $e = 0$ results in the probability of survival, P_s , being equal to 1 when no load is applied to a coupon. While this is a reasonable expectation, the accuracy of fit in the range of the data is often sacrificed. At the same time, the resultant extrapolative estimates of strength and fatigue life at $P_s > 0.90$ may still be intolerably conservative. Therefore, in many cases by setting $e = 0$ little may be gained, and much lost. This problem is most critical for fatigue life data.

The problem of correctly extrapolating composite fatigue data is presently one of conjecture. This is due to three deficiencies: 1) lack of large laboratory data sets for evaluating extrapolation from small subsets; 2) lack of experimental data which correlates laboratory coupon results with structural test results; 3) lack of field service experience. Therefore, while e should be greater than or equal to zero if it is truly a threshold parameter, correct values can not be determined at this time. Thus, setting $e = 0$ reduces the accuracy of our calculated fit to the data set but most likely results in extrapolative predictions being too conservative.

A possible solution to these problems has been suggested by Bowie, Besari, and Trapp^{K7} and will be discussed below. The resultant analytical solutions closely fit the data and avoid the problems of ME and MLE solution procedures. The resultant functions are not of extrapolative value, but this is not considered to be pertinent for comparison of data sets. Significant statistical analysis effort combined with extensive experimental investigations are needed before any extrapolative procedure can be developed and used with confidence. Hence, using a procedure which does not allow for extrapolation is not considered at the present time to be detrimental.

K.3 DESCRIPTION OF SELECTED ANALYSIS PROCEDURE

The particular form of Weibull analysis used in this report has been discussed in detail elsewhere^{K7,K8}. Essentially, this procedure which consists of linear regression analysis in Z variate space, is similar to that used by Talreja^{K3}. The analysis procedure used is described in this section.

In the analytic procedure used in this program, an initial estimate was made of the probability of survival based directly on the test results, in a staircase manner, $P(n_i)$, $i = 1, 2, 3, \dots, N$.

where

$$P(n_1) = 1 - 1/N$$

$$P(n_2) = 1 - 2/N$$

$$P(n_3) = 1 - 3/N$$

$$\cdot \quad \cdot$$

$$\cdot \quad \cdot$$

$$\cdot \quad \cdot$$

$$P(n_N) = 1 - N/N = 0.$$

The function $P(n_i) = 1 - i/N$ was selected instead of the alternate function, $P'(n_i) = 1 - i/(N+1)$. The difference $(P'(n_i) - P(n_i))$ diminishes as N increases. Thus for N equal to or greater than approximately 15, the difference is undetectable. However, if extrapolations to probability of survival in the range above 90% are to be attempted, the choice of $P(n_i)$ rather than $P'(n_i)$ as initial distribution is the more conservative approach^{K8}. This is especially true for N less than 15.

With the above approach, the initial distribution is defined as:

$$P(n_i) = 1 - i/N$$

and

$$P(n_{i+1}) = 1 - i/N \text{ if } n_{i+1} = n_i$$

otherwise

$$P(n_{i+1}) = 1 - (i+1)/N$$

In most other analysis procedures, $P'(n_i) = 1 - i/(N+1)$ is selected as the initial description without regard to replication of the type: $n_{i+1} = n_i$. The choice of assigning the same initial probability to different coupons with the same n_i was considered appropriate because they do actually form a local mode, within the limits of testing accuracy, of the sample distribution obtained by experiment.

The appropriate variables of Equation K1 are found by forming N-1 relations:

$$\begin{aligned}
 P(n_1) &= 1-1/N = \exp \left[-((n_1-e)/(v-e))^k \right] \\
 P(n_2) &= 1-2/N = \exp \left[-((n_2-e)/(v-e))^k \right] \\
 &\cdot \quad \cdot \quad \cdot \\
 &\cdot \quad \cdot \quad \cdot \\
 &\cdot \quad \cdot \quad \cdot \\
 P(n_N) &= 1-(N-1)/N = \exp \left[-((n_{N-1}-e)/(v-e))^k \right]
 \end{aligned}
 \tag{K8}$$

The last relation for N is not used since $P(N) = 0$.

The parameters of Equation 1 were found by reducing the relationships of Equation 8 to the linear equation:

$$Y = bX + a \tag{K9}$$

The three-parameter Weibull linear equation is:

$$\left[-\ln P(X) \right]^{1/k} = bX + a,$$

$$\text{where} \quad e = -a/b \tag{K10}$$

$$\text{and} \quad v = (1+be)/b.$$

For the two-parameter Weibull function ($e = 0$), the linear equation is:

$$\ln(-\ln(p(X))) = b \ln(x) + a, \tag{K11}$$

where

$$k = b$$

and

$$v = \exp(-a/b).$$

A linear regression method is used to determine k , e , and v . The initial

order distribution is:

$$P(X_i) = 1-i/N_p, i = 1, 2, 3 \dots N_p \quad (K12)$$

Regression coefficients are found by least square analysis of $N_p - 1$ equations such as:

$$\left[-\ln (1-i/N_p) \right]^{1/k} = bX_i + a, i = 1, 2, 3 \dots N_p-1. \quad (K13)$$

The sample correlation coefficient, R, is calculated as:

$$R = \frac{M \sum_{i=1}^M Y_i (aX_i + b) - \sum_{i=1}^M Y_i \sum_{i=1}^M (aX_i + b)}{\left[\left\{ M \sum_{i=1}^M Y_i^2 - \left(\sum_{i=1}^M Y_i \right)^2 \right\} \left\{ M \sum_{i=1}^M (aX_i + b)^2 - \left(\sum_{i=1}^M (aX_i + b) \right)^2 \right\} \right]^{1/2}} \quad (K14)$$

where $M = N_p - 1$

The coefficients of linear regression and alternative correlation coefficient r are calculated by means of the following steps:

$$S_x = \left[\frac{M \sum_{i=1}^M X_i^2 - \left(\sum_{i=1}^M X_i \right)^2}{M (M-1)} \right]^{1/2}$$

$$S_y = \left[\frac{M \sum_{i=1}^M Y_i^2 - \left(\sum_{i=1}^M Y_i \right)^2}{M (M-1)} \right]^{1/2}$$

$$b = \frac{\sum_{i=1}^M X_i Y_i - \left(\sum_{i=1}^M X_i \right) \left(\sum_{i=1}^M Y_i \right)}{\sum_{i=1}^M X_i^2 - \left(\sum_{i=1}^M X_i \right)^2}$$

$$a = \left(\sum_{i=1}^M Y_i - b \sum_{i=1}^M X_i \right) / M$$

$$r = b s_x / s_y$$

The standard deviation of the linear regression is calculated by means of the expression:

$$s = \left[\frac{(M-1)}{(M-2)} S_y^2 + (1 - r^2) \right]^{1/2}$$

The values of k , e , and v are found by iterating on $1/k$ in Equation K13 and maximizing R in Equation K14. An alternative procedure would be to match the sample skewness to the Weibull function skewness by iteration of $1/k$. The coefficient of skewness is given by:

$$c.o.s = \frac{\Gamma(1+3/k) - 3\Gamma(1+1/k)\Gamma(1+2/k) + 2\Gamma^3(1+1/k)}{(\Gamma(1+2/k) - \Gamma^2(1+1/k))^{3/2}} \quad (K15)$$

and recalling that $\Gamma()$ denotes the Gamma function.

There are two primary difficulties with the method employed. First, the resultant Weibull functions could be used to imply that in some three-para-

meter cases and at a given extrapolation, high probability of survival ($P_S > 0.95$), fatigue life decreases as applied stress amplitude decreases. Second, in the case of two-parameter analysis, probability of survival functions tend to predict overly conservative extrapolated fatigue lives, particularly at low applied stress amplitudes. Both of these difficulties refer to the extrapolative capability of the resultant functions. This is not considered a problem for comparing the data sets, and as discussed in Section K.2, extrapolation of the data does not appear to be presently feasible.

K.4 ALTERNATIVE PROCEDURES

Two other procedures are available for analyzing fracture data. They are the Standardized Variable Estimation (SVE) method^{K3} and the Modified Double Exponential Function (MDEF) method^{K7}.

In the SVE method^{K3} the standardized variable Z is defined as in Equation K6 for a Weibull survivorship function or as:

$$Z = \frac{X-e}{v} \quad (K16)$$

for a Weibull probability of failure function. Thus, as mentioned in Section K.1, the order statistics Z_i are independent of e and v and depend only on the shape parameter k . The expected value, EZ_i , median, MZ_i , and variance, VZ_i , of the order statistic Z_i have been derived by Lieblein. The characteristic values of Z_i depend only on the sample size, N , and the shape parameter, k ^{K3}. From Equation K16, we obtain^{K3}:

$$X_i = e + v EZ_i \quad (K17)$$

$$\text{or} \quad X_i = e + v MA_i. \quad (K18)$$

Equations K17 and K18 can be solved by linear regression. The shape

parameter k is the value for which the correlation coefficient is a maximum^{K3}. The parameters e and v are found as the X_i - intercept and slope of the best fit line^{K3}. If the sample data belong to different populations, this will result in the (X_i, EZ_i) and (X_i, MZ_i) scattering about different straight lines^{K3}.

Talreja^{K3} found that the SVE method provided accurate estimates of k , e , and v , for low values of k . At higher k values, the method often gives negative estimates of e . The procedure gave more accurate estimates of the parameters than the ME and MLE methods^{K3}.

The MDEF is based upon the double exponential function of Gumbel^{K1}. In this procedure^{K7}, for a set of sample fatigue lives, N_p , the initial distribution is defined by:

$$P(X_1) = 1 - 1/(N_p + 1) \quad (K19)$$

and

$P(x)$ by:

$$P(X) = 1 - \text{Exp} [-\text{Exp} [-\alpha_0 (X-u)]]. \quad (K20)$$

For lives greater than u , the above function is used as described by Gumbel^{K1}. For lives less than u , α is a function of the life, X , where:

$$\alpha(X) = \alpha_0 \left[\frac{\ln u - \ln X_0}{\ln X - \ln X_0} \right] \quad (B21)$$

The parameter X_0 is defined as the threshold fatigue life. For $X \leq X_0$, P_S is defined as equal to unity. The modified double exponential function (MDEF) can be solved by ME, MLE, or LR procedures. The best procedure appeared to be linear regression^{K7}. The MDEF function was found to not only fit the sample data with high correlations, but to provide procedures for exploration of data extrapolation accuracy^{K7}.

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